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Commencement Bay Nearshore/Tideflats Superfund Site, Tacoma, Washington Remedial Investigations. Evaluation of Alternative Dredging Methods and Equipment Disposal Methods and Sites, and Site Control and Treatment Practices for Contaminated Sediments

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Alternative technologies and techniques for dredging, disposal, and treatment of contaminated sediments are reviewed. Implications of alternative technologies for management of contaminated sediments are discussed. Selection of appropriate technologies for contaminated sediments management depends on the physical and chemical profile of the sediments, and particularly on the physical state (liquid, solid, or gaseous) of contaminants of concern and changes in state that may occur at different phases of dredging, disposal, control and treatment. Determination of acceptable criteria governing concentrations of contaminants in water, sediments and soils, and air is the major requirement for selecting specific technologies for managing contaminated sediments. Technologies should be used which ensure that criteria will be met at all phases in the handling operations. Cost is most variable for disposal site effluent treatment options.

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Evaluation of Alternative Dredging Methods and Equipment, Disposal Methods and Sites, and Site Control and Treatment Practices for Contaminated Sediments

PREPARED FOR:
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REMEDIAL INVESTIGATIONS

EVALUATION OF ALTERNATIVE DREDGING METHODS AND EQUIPMENT, DISPOSAL METHODS AND SITES, AND SITE CONTROL AND TREATMENT PRACTICES FOR CONTAMINATED SEDIMENTS

PREPARED FOR:

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PREPARED BY:

SEATTLE DISTRICT
U.S. ARMY CORPS OF ENGINEERS
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EXECUTIVE SUMMARY

The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the U.S. Environmental Protection Agency to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removal and handling of contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of contaminated sediments located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments. By agreement with WDOE, the Seattle District, U.S. Army Corps of Engineers, prepared this report to describe and evaluate alternative dredging methods and equipment, disposal methods and sites, and site control and treatment practices for contaminated sediments derived from Commencement Bay. These alternatives are evaluated based on the following factors:

- Cost of each alternative.

- Degree of confinement and release of volatile, soluble, and sediment-bound contaminants resulting with each alternative.

- Considerations and limitations specific to each alternative (e.g., equipment and site availability, method efficiency, equipment depth limitations, sociopolitical concerns, and other indicators of practicability).

Dredging methods and equipment are evaluated in terms of availability, production rates, and contaminant containment during use. Characteristics, operational considerations and control, and equipment considerations and modifications for dredging contaminated sediments are described for each dredging alternative. The two basic types of dredges addressed in this report, hydraulic and mechanical dredges, are categorized based on the similarities each have in terms of contaminant loss during dredging. Special-purpose dredges that have been designed for contaminated sediments are included in the hydraulic dredge category.

Three generic disposal methods, open-water, upland, and nearshore, are examined in terms of their strengths and weaknesses in successfully containing the various contaminant classes. Specific potential disposal sites in the Commencement Bay area, identified for this report, are discussed and evaluated for their ability to meet the anticipated needs for disposal of contaminated sediments. Additionally, options and limitations for offsite disposal are briefly addressed.

Site control measures and treatment practices addressed in this report pertain to contaminant confinement within a selected area, isolation from the environment, and removal from liquid or gas effluents during and after disposal of contaminated sediments. In addition to site control and treatment, discussions are presented on biological control of disposal areas and appropriate monitoring requirements for each disposal method, as well as remedial response to monitoring indications.

The costs of alternative dredging methods, disposal options, and treatment methods are discussed in chapter 5. This chapter describes the principles and ranges of costs for the technologies and procedures discussed in this report and illustrates comparisons between various technologies and management options on the basis of cost. Little cost information is available for the application of treatment technologies due to the scarcity of investigations on the applicability to treatment of dredged materials and the many site-specific factors involved. Therefore, the costs of treatment at various levels of contaminant removal are estimated for representative upland and nearshore sites, in order to illustrate cost factors affecting decisions concerning appropriate treatment levels, and disposal areas.

In chapter 6.0 this report compares and discusses these various alternatives, presenting those conclusions that can be formulated at this stage of planning for Commencement Bay. First, preferred dredging methods and possible tradeoffs for various types of sediment contamination are addressed. Disposal methods are ranked in terms of the major factors that would influence decisions on disposal of contaminated sediments. The likely applicability of treatment methods to Commencement Bay is discussed. Second, the relative contaminant loss or confinement obtained during each stage of the handling process (dredging, disposal, control, and treatment) is discussed. Third, disposal sites are evaluated and recommendations on preferred or most appropriate sites for near-term consideration are presented. Fourth, information needs and data gaps for handling of contaminated sediments are identified. Research or tests that merit priority consideration at this time are discussed. In addition, as a way of highlighting key steps and considerations in selecting dredging and disposal methods, available information is applied to a case study contaminated sediment from Commencement Bay.

In terms of sediment resuspension at the dredge site, special-purpose hydraulic dredges produce less resuspension than conventional hydraulic dredges, and with the exception of hopper dredge overflow, conventional hydraulic dredges produce less resuspension than mechanical dredges. In terms of slurry water that may require treatment at the disposal site, mechanical dredges produce much less water than special-purpose hydraulic dredges, and special-purpose dredges produce less water than conventional hydraulic dredges. Hydraulic dredges produce less solids resuspension at the dredging site and have a higher removal efficiency for liquid and solid phases than do mechanical dredges. However, use of a hydraulic dredge to obtain high removal efficiency at the dredging site involves a tradeoff requiring consideration of increased slurry water and sediment consolidation time at the disposal site.

Different dredging methods appear more appropriate for certain contaminant classes:

- For volatile contaminants, mechanical dredges are likely to produce less loss than hydraulic dredges.

- Sediment-bound contaminants can be removed more efficiently by hydraulic dredges than by mechanical dredges and appropriate technology exists for control of solids at the disposal end.

- Soluble contaminants can be removed more efficiently by a hydraulic dredge, but are difficult to control at the disposal end and treatment of the effluent water may be required.

Most projects are likely to contain all three types of contamination, confounding a decision on appropriate dredging technique. In terms of overall contamination, sediment-bound contaminants usually represent the bulk of the contamination, suggesting use of hydraulic equipment for maximum recovery and extraction efficiency. The amount of volatiles that may be lost during dredging are not likely to be a source of major concern in many projects. As the types and amount of soluble, or easily solubilized, contaminants increase in a sediment to be dredged, greater consideration should be given to the cost and environmental impact of mechanical dredging with watertight equipment relative to that of hydraulic dredging and water treatment at the disposal site. This evaluation is likely to be the key to selecting a dredge for a given contaminated sediment.

A variety of dredging equipment modifications are appropriate for work in contaminated sediments. Modifications that appear most promising at this time include:

- the walking spud (hydraulic dredge),

- ladder pumps (hydraulic dredge),

- in-line production meters (hydraulic dredge),

- large, watertight buckets (mechanical dredge), and

- degasser collection and treatment (in dredge furnace or other) system (hydraulic dredge).

Operational modifications to be considered for hydraulic cutterhead dredges include minimizing cutter revolution speed, controlling swing speed, and not overdigging the maximum cut depth. For mechanical dredging, sweeping the bottom with the bucket and digging fine-grained sediments from underneath (heavy buckets penetrating through soft surface materials) are practices to be avoided in contaminated areas. For most operator controls or operational modifications, serious consideration should be given to hourly rental of dredging equipment rather than bidding in order to maintain control of project costs and better define cost factors during first-time use of modifications.

The key considerations involved with disposal method effectiveness are:

- the class of contaminants of concern,

- the similarity of the disposal site condition to *in situ* conditions,

- the number and magnitude of contaminant transport mechanisms operating at the disposal site,

- the degree of control or treatment possible to intercept migrating contaminant fractions, and

- the risk of significant adverse effects from contaminants released by the disposal method.

Heavy metals often will go into solution and become mobile in oxidized, unsaturated sediments (e.g., in an upland site). Organic contaminants tend to remain partially soluble regardless of how wet or dry the sediment stays. Therefore, they will have greater mobility where greater exchange of water within the sediments occurs. Nearshore sites have greater water exchange than upland, and upland has greater exchange than open water. These tendencies would suggest that heavy metal contamination be left under water and consideration be given to placing organics contamination above water.

In general, leaving, or disposing of, contaminated sediments in a chemical environment as close as possible to their *in situ* state favors contaminant retention (especially metals). Geochemical changes associated with air and oxygen in upland and nearshore sites can change sediment pH (mobilizing metals) and alter (dissolve, degrade, or volatilize) sediment organic carbon (mobilizing organics). Based on this, many contaminants would tend to stay bound to sediments better in an open-water, capped site than a nearshore or upland site. (For organic contaminants, the influence of geochemical changes may be outweighed by the consideration of water exchange.)

Open-water sites, especially those in deep water, have fewer transport mechanisms (e.g., air is absent) than upland sites. Nearshore sites have the most transport routes available and are located in a very active environment; therefore, nearshore disposal is the least preferred method for long-term confinement of contaminants.

In terms of controlling contaminant release, open-water disposal allows for very few controls of releases other than cap thickness. However, increasing cap thickness is a relatively simple and effective control method. Upland disposal, on the other hand, allows for the greatest control through design features, monitoring capabilities, backup contaminant intercept systems, and treatment facilities. The nearshore disposal option does allow for some greater control of contaminants than in open water, but many fewer than are available in an upland situation.

For open-water disposal, the levels of contaminant concentration released will be low relative to nearshore or upland sites and will be diluted by the overlying water. The risk of significant damage in this environment is low and would not likely affect human health. For upland disposal, environmental risks incurred may be higher than in open water because of potential human health concerns. For nearshore disposal, the risks to the environment and to human health are much greater than in open water and in many situations are greater than at an upland site.

As an overall generalization, and looking ahead to development of criteria for appropriate disposal methods, the interplay of site control and contaminant mobility suggests that nearshore sites should receive the low-level contamination, open-water sites the low-to-medium-level contamination, and upland sites the high-level contamination.

In going from upland to nearshore to open-water disposal, the degree of site control and the number of available treatment options decreases. This decreasing control is translated into reduced opportunities to design additional treatment measures that would prevent sudden or accelerated contaminant releases into the environment and/or to avoid the extreme expense of sediment removal and relocation.

Potential treatment at upland sites includes several methods that cannot be implemented at nearshore sites without site dewatering. Dewatering would require extraordinary and extremely expensive construction techniques and is, therefore, not considered here. Foundation material in the nearshore zone may not be adequate to support the necessary diking. Seismic potential, mud foundations, and tidal fluctuations can threaten dike stability. As a result, construction in the nearshore zone has a higher risk of failure. Therefore, equivalent treatment in each site would produce lower containment of contaminants in the nearshore site due to the factors operating on contaminant mobility and the limited site control relative to upland sites.

Four levels of treatment of slurry, runoff, and leachate water were identified as follows:

- Level I is the removal by sedimentation of suspended solids and particulate bound contaminants from disposed and site-derived water. This level would remove 99.9 percent of solids, 80-99 percent of heavy metals, and 50-90 percent of organic contaminants. A representative cost for Level I treatment of 1,000,000 cubic yards (c.y.) of dredged material at an upland site is $18 million (total project cost, including dredging).

- Level II is additional treatment to remove soluble metals. This level would increase heavy metals removal to 99 percent. A representative total project cost for 1 million c.y. at Level II treatment is $19,000,000.

- Level III is treatment to remove soluble organics. This level increases organics removal to 95 percent. A representative total project cost for 1 million c.y. at level II treatment is $25 million.

- Level IV is final stage treatment to remove dissolved solids. This level would increase organics removal to 99 percent, but is primarily designed to remove nonmetallic, inorganic contaminants (e.g., nutrients and common anions). Of the Level IV treatment systems, distillation is the most expensive, best documented, and best performing process available. A representative cost for 1 million c.y. treated at level IV is $49 to $79 million.

For Levels I and II treatment methods, the cost of plain sedimentation represents a major investment relative to chemical clarification, filtration, and metals precipitation. The addition of these latter treatment methods may be relatively cost effective measures of obtaining substantial additional contaminant removal. Level IV treatment is only a likely consideration for site runoff and leachate, where the alternative of using an existing municipal or industrial facility may be available and should be evaluated. Treatment Levels II-IV require further experience in dredged material applications before their performance can be fully documented with this medium.

Treatment measures discussed in this report do not involve, with one exception, the destruction of contaminants. Instead, contaminants are concentrated by the treatment process. Therefore, treatment designs must account for disposal of treatment sludges and spent fluids.

For hydraulic dredging, the relative importance of losses at various times and from various phases during the sediment dredging and disposal process is shown below, listed in order of decreasing importance:

(1) Short-term loss of sediment and water.

(2) Long-term loss of water.

(3) Short-term loss of volatiles.

(4) Long-term loss of volatiles.

(5) Long-term loss of sediment.

Normally, disposal will result in greater short-term loss of sediment and water than will dredging. Based on the above ranking of importance, short-term sediment and water loss during disposal will be the usual first consideration and the basis for selecting disposal method and treatment level. Concurrently, but on a secondary basis, the contribution of dredging to this loss should be evaluated. The next subsequent step should be selecting appropriate treatment, monitoring, and remedial response to address long-term loss of waterborne contaminants. Consideration of items (3)-(5) above would depend on sediment and site-specific conditions.

For mechanical dredging, short-term loss of sediment and water and long-term loss of water from the disposal site (for upland or nearshore sites) may be equally important. The proportion of partially soluble contaminants in disposed sediment that is available for later leaching is increased relative to that in hydraulically dredged sediments. The amount of sediments and easily soluble contaminants lost during dredging is also increased relative to hydraulic dredging. However, the use of watertight buckets may reduce this loss substantially.

Several open-water, upland, and nearshore sites with high potential of near-term use for contaminated sediments are recommended for first consideration in subsequent planning. For open-water sites, further evaluation of the Hylebos/Browns Point site is recommended because of the potential for more complete containment of sediments. No further evaluation is recommended for the Puyallup River delta. For upland sites, Port of Tacoma "D" and the Puyallup

River/Railroad sites are the most worthy of further evaluation. Their capacities are large, the sites are within pumping distance from a variety of Commencement Bay dredging sites, and the sites are sufficiently large to permit onsite treatment facilities to be constructed. For nearshore sites, further evaluation of Milwaukee Waterway, the Blair Waterway slips, and the Blair graving dock sites is recommended. Information needs and recommended studies identified in this report are summarized below.

o Additional experience and prototype work is needed for several aspects of aquatic disposal of contaminated sediments. Capping of contaminated sediments should be demonstrated using equipment, sediments, and material available in Puget Sound. For nearshore and open-water, confined disposal, experience in placing underwater clay liners is needed. The vertical diffuser should be demonstrated in the United States.

o Loss of volatile contaminants through degasser systems on hydraulic dredges should be investigated. Potential loss should be estimated by obtaining field information on the volume of gas in the sediments in situ. Actual loss should be studied by monitoring of degasser discharges.

o The availability of special-purpose dredges could be a major consideration in their use in Commencement Bay. Due to the advantages that these plants offer, specific determinations of their potential availability are warranted at this stage of planning.

o Additional planning will be needed before the list of potential disposal sites can be pared down to those that are probable for designation. The generic information needs identified for each type of disposal site should be pursued as part of ongoing planning in Commencement Bay. In addition, many site and treatment design requirements can be obtained from sediment tests at this time.

o Better quantitative prediction of contaminant mobility can be obtained by conducting pilot-scale laboratory tests to develop empirical relationships of contaminant mobility under various disposal conditions in combination with the use of mathematical models to predict this mobility. Tests to measure long-term contaminant mobility for the three disposal methods and resulting conditions, and first-stage modeling of mobility, should be considered at this time.

The broader conclusions and recommendations of this report are provided below:

o The limited disposal capacity, the variable levels and types of sediment contamination, the multiple locations of dredging, and the anticipated large volume of contaminated dredged material strongly suggest that any one solution or one type of disposal site will not suffice for Commencement Bay. For near-term stages of planning, sites in open water, nearshore, and upland should all be pursued for potential use. This "mixed" approach will also allow maximum flexibility in defining appropriate criteria and standards.

o Large, centralized disposal sites and treatment facilities should be established for use by those with dredging requirements. The site(s) should be managed by a single entity and be designed to meet criteria established by a bay-wide management plan. Conceptually, the high initial cost for acquiring and developing the disposal site and any associated treatment facilities would be spread between the dredgers and prorated at an unit cost per each c.y. disposed. This solution would amortize the expense of initial construction over time as well as spreading the cost among users; and it would result in less land being impacted and, therefore, fewer disruptions in land use. Site monitoring and potential remedial response (mitigation) costs would also be reduced. Development of a management plan that matches disposal resources to dredging needs would be a complex and difficult task. For large volumes of contaminated material, such as occurs in Commencement Bay, this may be the only practicable solution.

- Since treatment costs are very expensive, it would be prudent to treat only those volumes of sediment that meet or exceed the levels that trigger the need for treatment. This selective dredging and disposal allows maximization of a limited disposal capacity. However, in order to accomplish this, sediment characterization may require more samples (at greater cost) than typically analyzed for many dredging projects. At the same time, this characterization and subsequent segregation must bear in mind the precision of the dredging equipment employed.

- Dredging projects involving contaminated materials often encounter sediments comprised of mostly coarse (sand and gravel), clean material with a small fraction of fine (silt and mud), contaminated material. Separating these materials can substantially reduce the volume of contaminated material that requires special handling and treatment. A separation facility would take the effluent from a hydraulic slurry and settle out coarse material first. This material could be removed for use in a number of ways. The remaining fines are settled into a secondary basin or removed during appropriate effluent treatment. The cost of segregation and rehandling may be compensated for by the reduced cost associated with treating and confining a lesser volume of contaminated sediment.

- The common theme of dredging, disposal, control, and treatment discussions is the identification of pertinent decisionmaking criteria. These should define testing methods and interpretation of test results to determine when certain dredging and disposal options are appropriate and required. Development of criteria represents the central link between available disposal sites, the extent and types of sediment contamination, and the navigation and Superfund needs to move that sediment. The criteria will allow assembly of the components of a dredging job: type of dredge, disposal site, and treatment levels, and are at the core of a management plan for Commencement Bay. Therefore, development of criteria should receive primary attention in any future efforts.

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CHAPTER 1.0 INTRODUCTION

1.01 Background. The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the U.S. Environmental Protection Agency (EPA) to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removal and handling of contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in the nearshore areas of Commencement Bay may require dredging and disposal of contaminated sediments. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments. By agreement with WDOE, the Seattle District, U.S. Army Corps of Engineers, conducted an analysis of alternative dredging and disposal methods with potential application to Commencement Bay. This draft report contains the alternatives analysis.

1.02 Scope of This Report. The Commencement Bay Nearshore/Tideflats Superfund Site includes portions of the communities of Ruston and Tacoma, the western shoreline of the bay, and the land and nearshore water areas around the various waterways of the bay (plate 1). While the boundaries of the site may change as new information becomes available, the waterward limit of the site is presently defined as the water depth contour at -60 feet mean lower low water (MLLW).

This report describes and evaluates alternative dredging methods and equipment, disposal methods and sites, and site control and treatment practices for contaminated sediments derived from Commencement Bay. These alternatives are evaluated based on the following factors:

- o Cost of each alternative.
- o Degree of contaminant confinement and release resulting with each alternative.
- o Considerations and limitations specific to each alternative (e.g., equipment and site availability, method efficiency, equipment depth limitations, sociopolitical concerns, and other indicators of practicability).

This report solely addresses contaminant removal from those portions of the Superfund site that are under water (intertidal and subtidal to -60 feet MLLW). Removal of contaminated soil or materials from upland areas is not addressed. The remedial technologies discussed in this report pertain to dredging and disposal, including capping, of contaminated sediment that has been dredged and relocated. In-place remedial actions, such as placement of barriers to block underwater contaminant seeps into the waterways or capping of contaminated materials *in situ* under water, are *not* addressed.

1.03 Report Organization. Dredging techniques and technology are discussed in chapter 2. Disposal methods and sites are discussed in chapter 3. Possible treatment methods for contaminated sediments and water are discussed in chapter 4. The costs of dredging, disposal, and treatment alternatives are presented and summarized in chapter 5. Chapter 6 summarizes the relationships between the alternatives and presents those conclusions that can be formulated at this stage of planning for Commencement Bay.

1.04 Report Assumptions. The following assumptions underlie the evaluation of alternatives discussed in this report.

o The physical characteristics (e.g., grain size) of the sediment to be dredged are within the range typically reported for the Commencement Bay nearshore area.

o The sediment to be dredged is not classifiable as "dangerous" or "extremely hazardous" pursuant to the Resource Conservation and Recovery Act (RCRA) or the State of Washington Dangerous Waste Regulations.

o The sediment to be dredged is not acceptable for unconfined, open-water disposal due to the presence of contamination exceeding criteria. These criteria are considered to be presently unspecified (although WDOE has established interim guidelines for consideration).

o In the absence of specific sediment contamination criteria, the removal and handling of contaminated sediments is evaluated in terms of maximum confinement and minimum release or redistribution of contaminants.

o For purposes of discussion in this report, contaminants are loosely classified as volatile, soluble, or sediment-bound. Contaminant evaluations are based on these classifications.

o Cost analysis of alternatives is based on an "order-of-magnitude" precision using costs incurred on similar projects, estimates of costs associated with implementing a typical dredging project, and/or relative cost values. Due to the number of factors that influence cost, ranges of cost are occasionally presented. However, attempt has been made to relate cost principles to specific Commencement Bay considerations.

1.05 Relation of This Report to Other Work. For the Commencement Bay Nearshore/Tideflats Superfund Site, this report constitutes an evaluation of potential remedial technologies for clean-up of contaminated sediments. As part of the remedial investigations, the WDOE is conducting a separate study to define the extent of contamination at the site. A central component of the study includes development of decision criteria for identifying "problem" sediments that are sufficiently hazardous in place to warrant removal. This report addresses options for removal and disposal of these sediments.

While generally effective methods can be identified, specific recommendations for dredging, disposal, and site control methods are difficult to make without first defining the criteria that need to be met or without having some project specific information (e.g., location, quantity of dredged material, size of disposal site). Therefore, the basic intent of this report is to display and evaluate alternatives that should be considered in selecting appropriate dredging and disposal methods once criteria are available. Moreover, this display of alternatives can assist in establishing criteria that are technically feasible and for which the cost of meeting specific criteria has been considered.

As a related task, the Corps of Engineers is developing a decisionmaking framework for disposal of contaminated sediments derived from Commencement Bay. The framework is being prepared by the Corps' Waterways Experiment Station (WES), under agreement with the Seattle District and WDOE. It will specify testing requirements and methods to evaluate sediment contamination, and will define test result interpretation to determine when various disposal controls and restrictions (described in this report) are required.

1.06 Classification of Commencement Bay Contaminants. As mentioned above, this report addresses contaminant confinement and release during dredging and disposal in terms of three generalized contaminant classes: volatile, soluble, and sediment-bound. These classes generally refer to the phase (gas, liquid, solid) for which a contaminant has a relatively greater affinity and in which higher concentrations might be expected during the dredging and disposal process. This classification is done in full recognition that contaminants will partition and move between these phases to differing extents based on a number of factors (appendix 1). The factors that govern contaminant partitioning, mobility, and consequent loss during dredging and disposal are discussed briefly in the following chapters and in appendix 2 of this report. Contaminant specific information is unavailable for many contaminants and dredging disposal methods. Additionally, site-specific conditions will influence the amount of a contaminant found in any one phase. Therefore, no specific list of contaminants is identified for each class, and the classification is used solely as a basis for comparing dredging and disposal alternatives based on existing data and information. Appendix 1 provides a ranking of certain organic contaminants found in Commencement Bay in terms of their relative tendency to move from sediment-bound to soluble or volatile phases. Chapter 6 illustrates application of partitioning concepts to a case study from Commencement Bay.

CHAPTER 2.0 DREDGING METHODS AND EQUIPMENT

2.01 Introduction. This chapter describes dredging methods and equipment and evaluates them in terms of availability, production rates, and contaminant containment during use. Characteristics, operational considerations and control, and equipment considerations and modifications for dredging contaminated sediments are described for each dredging alternative. Costs of dredging alternatives are summarized in chapter 5.

2.01.01 Principles of Dredging. Dredging equipment and methods have been developed over the years to enhance one of the two basic uses of dredging:

a. Underwater excavation to provide or maintain navigable water depths in harbors and channels.

b. Underwater mining and sand and gravel production.

The dredging process itself involves four basic tasks: (1) the loosening or dislodging of sediment by mechanically penetrating, grabbing, raking, cutting, drilling, blasting, or hydraulically scouring; (2) a lifting action accomplished by mechanical devices such as buckets or by hydraulic suction; (3) the transporting of dredged material by pipelines, scows, hopper dredges, or trucks; and (4) disposing of the material by either discharging from a pipeline or by dumping from trucks into a confined disposal area, bottom dumping from barges, or pumping out of scows or hoppers. In some hydraulic operations all four actions are carried out continuously and concurrently by a single piece of equipment, but in others the various functions are performed separately and intermittently, utilizing two or more pieces of equipment. For instance, where dredging equipment does not have on-board storage capability or where environmental considerations preclude the possibility of disposing of the material into open water adjacent to the dredging site, auxiliary equipment (scows or barges) is required for storage and transport of the dredged material.

Dredging practices in the United States have evolved to achieve the greatest possible economic returns through maximizing production with only secondary consideration given to environmental or esthetic impacts. The type of equipment and methods used in a given job traditionally have been based on the following very practical considerations:

- o Amount of sediment to be dredged.
- o Physical characteristics of the dredged material.
- o Water depths and hydrologic characteristics.
- o Dredged material disposal considerations (type and location of sites).
- o Availability of dredging equipment.

Dredging of contaminated sediments requires the additional consideration of contaminant loss during the extraction process and meeting of applicable criteria pertaining to removal efficiencies and/or environmental protection. For most jobs, the controlling factors in equipment selection are the degree of contaminant confinement required and the cost necessary to achieve this confinement. For any given dredging method, technologies and practices exist that increase contaminant removal and confinement, though confinement efficiencies will vary greatly between techniques. Therefore, the critical element in the selection of a dredging technique is the definition of criteria that are to be met. These criteria may specify removal efficiencies, allowable losses, emission rates, and/or concentrations for individual contaminants, allowing a variety of dredging techniques to be considered, or the criteria may specify certain equipment or method as requisite for given levels and types of contamination. Other than through exercise of judgment, recommended techniques are difficult to determine prior to consideration of these criteria.

Many operational modifications and controls that can be used for working in contaminated sediments are not standard or accepted practices. Therefore, contractors bidding on a job requiring these modifications may feel the need to protect their job profits by increasing bids. A solution to this cost escalation effect is hourly rental rates until the operators gain experience in use of a specific control practice. Better cost control can result with this approach.

The principles and specifics of dredging costs are discussed in chapter 5, except where cost information is used in demonstrating calculations of dredging productivity.

2.01.02 Types of Dredges. Dredging equipment and its nomenclature resist precise categorization. As a result of specialization and tradition in the industry, numerous descriptive, often overlapping, terms categorizing dredges have developed. For example, dredges can be classified according to: the basic means of moving material (mechanical or hydraulic); the method of storage or disposition of dredged material (pipeline or hopper); the device used for excavating sediments (cutterhead, dustpan, plain suction); the type of pumping device used (centrifugal, pneumatic, or airlift); and others.

Two basic types of dredges, hydraulic and mechanical, are addressed in this report. These descriptive categories were selected based on the differences each have in terms of contaminant loss during dredging.

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost *in situ* densities. Clamshell, dipper, dragline, and ladder dredges are types of mechanical dredges.

Hydraulic dredges remove and transport sediment in liquid slurry form. They are usually barge mounted and carry diesel or electric powered centrifugal pumps with discharge pipes ranging from 6 to 48 inches in diameter. Cutterhead, suction, dustpan, hopper, and "special-purpose" dredges are types of hydraulic dredges. "Special-purpose" dredges, for this report, are dredges designed to pump high solids concentrations and/or produce low turbidity levels.

2.01.03 Dredging Techniques Not Evaluated in This Report. Because this report focuses on dredge applications to removal of contaminated sediments, the evaluation focuses on maximizing contaminant and solids removal and containment, cost and production rates, and equipment availability. Dredge types, operational practices and equipment modifications that produce relatively high suspended solids concentrations at the extraction site in the water column, and high or additional costs without distinct advantages, are not evaluated in this report. These alternatives and the reasons for excluding them are briefly described below.

Agitation dredging is the process of suspending bottom sediments in the water column and allowing currents to carry them from the project area. Because of the assumption that material to be dredged is unacceptable for unconfined, open-water disposal, this dredging technique is not included for evaluation. For the same reason, sidecasting disposal of dredged sediment is not considered.

The orange-peel dredge is a mechanical dredge with a modified bucket. The bucket consists of four moving parts (as opposed to two for the clamshell bucket) and is designed primarily for handling rock. The orange-peel dredge results in higher loss of water and sediment during dredging and lacks any distinct advantage over the more common clamshell bucket.

The bucket ladder dredge is a mechanical dredge that utilizes an endless chain of buckets that loop around two, structurally-held tumblers. Developed primarily for mining and handling of coarse material, this dredge has very limited and diminishing availability, a high first cost, and produces high suspended solids concentrations in the water column during extraction.

Dragline dredges are shore-mounted, mechanical dredges that use a bucket and wire rope to pull or drag sediment along the bottom. This technique produces high suspended solids concentrations during dredging and only average removal efficiencies.

Dipper and backhoe dredges are mechanical dredges with a ladder and bucket operated by hydraulic cylinders. Their production rates are similar to other mechanical dredges, but they produce relatively high levels of suspended solids in the water column and are more expensive to use.

The Japanese have developed a submerged discharge system for overflow from hopper dredges known as the antiturbidity overflow system (ATOS). ATOS was developed to reduce surface turbidity in receiving waters by discharging the overflow directly into subsurface waters, but this system does not reduce overall resuspension of sediment.

2.02 Hydraulic Dredges. All hydraulic dredges have one thing in common; they use a pipeline to move the slurried dredged materials. A pump supplies the force to transport the slurry (dredged materials and water) through a pipeline from the channel bottom to the discharge point. Hydraulic dredges can discharge the dredged materials into a hopper or bin on the dredge itself, into barges tied alongside or pump the dredged material long distances (up to 2 miles) to open-water, nearshore, or upland disposal sites.

2.02.01 Pipeline Cutterhead Dredges. The most common type of dredge used in the United States and the Pacific Northwest today is the pipeline cutterhead dredge. Because of its high potential for use in Commencement Bay, and because it is the basic dredge type to which many of the contaminant related modifications have been applied, a detailed explanation of this type of dredge and its components is given. It has the advantage of being able to excavate materials, move them hydraulically, and dispose of them without rehandling. These dredges are generally classified by size in accordance with the diameter of the discharge pipeline: small class pipeline dredges have a 4-inch to 14-inch discharge; medium class pipeline dredges have a 16-inch to 22-inch discharge; and large class pipeline dredges have a 24-inch to 36-inch discharge. Typical specifications for five sizes of pipeline dredges are shown in table 2-1.

a. Description of Equipment. Figure 2-1 shows the major components of a pipeline cutterhead dredge. These components consist of a cutterhead on the end of a suction pipeline, a ladder structure supporting the suction pipeline and cutterhead, support frames (A and H) for the ladder, hoisting equipment, main pump and main engine, the spud and support gantry, and a floating discharge pipeline. Photographs 2-1 and 2-2 show the forward components of the cutterhead dredge and the spud gantry, respectively.

o Cutterhead. The cutterhead is the most forward component of the dredge. It is basket shaped, with spiral blades forming the sides of the baskets as shown in figure 2-2 and photograph 2-3. It rotates slowly at a speed of 5 to 30 revolutions per minute (r.p.m.) while the blades loosen materials to be dredged.

A secondary purpose of the cutter is to prevent large debris from entering or plugging the intake pipe. Cutter diameters vary from less than 2 feet for a small dredge and up to 10 feet for a large dredge. The many types of cutterheads and modifications to cutters allow efficient dredging of all types of materials. Pick-type teeth can be added to facilitate dredging in hard packed materials, coral, and soft rock.

o Ladder and Suction. The ladder is a heavy triangular steel frame extending forward from the hull. The dredge cutter is attached to the forward end of the ladder. Winch gear attached to the A frame raises or lowers the cutter end of the ladder. The suction pipe runs from the center of the cutterhead through the ladder to the dredge pump. Suction diameters are usually equal to or slightly larger than the dredge discharge pipeline diameter.

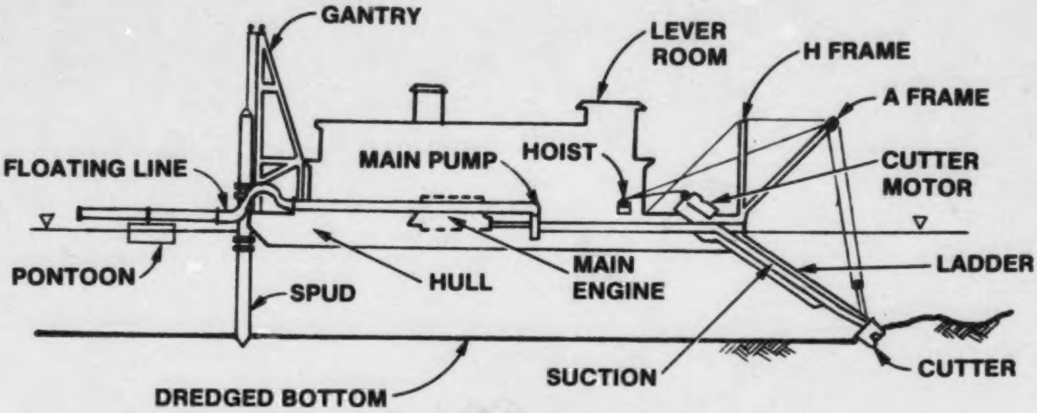
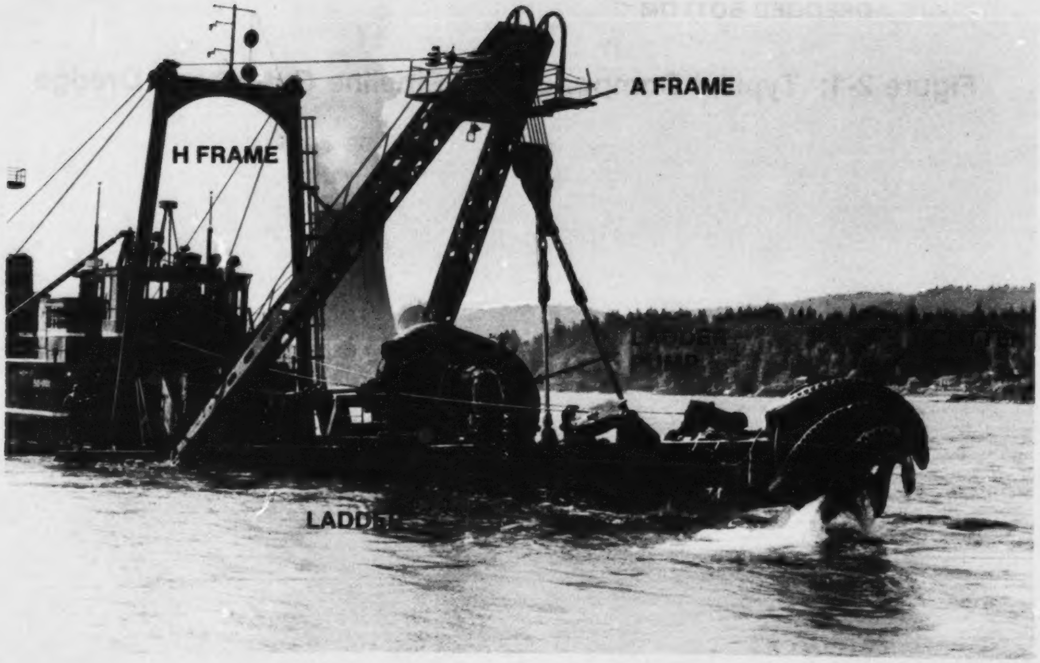
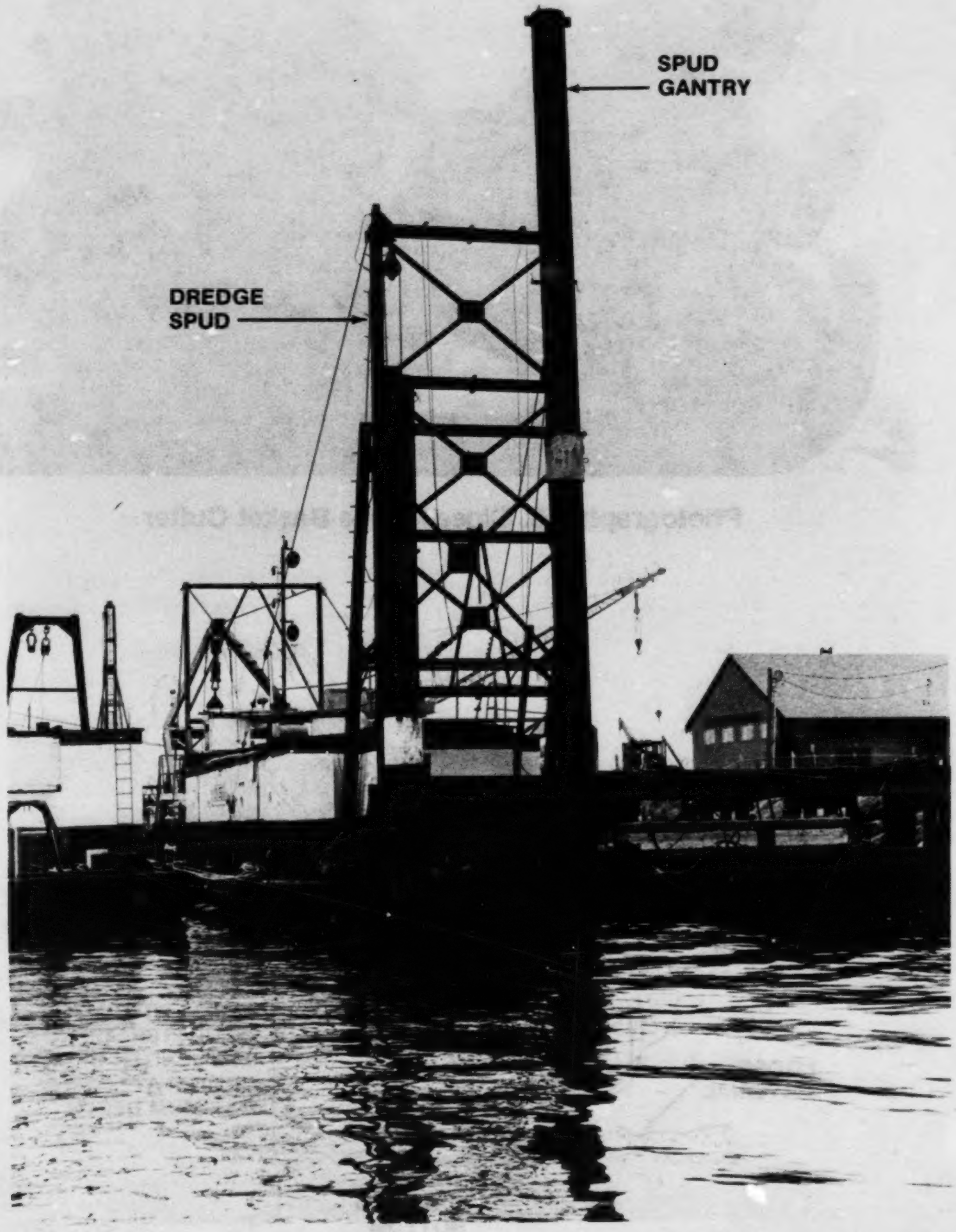


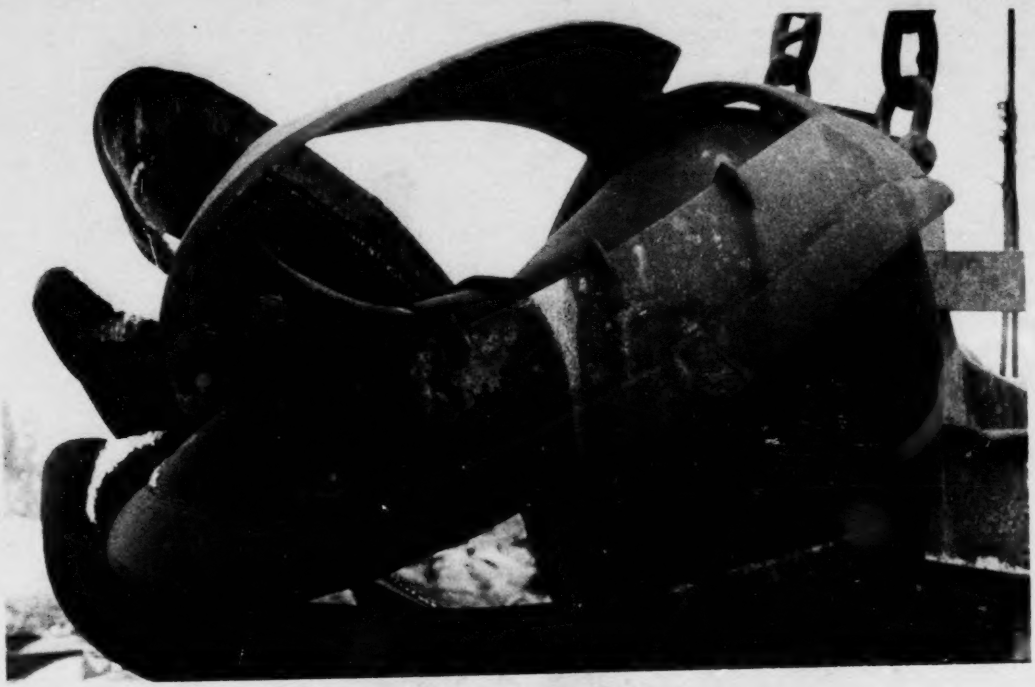
Figure 2-1: Typical Components of Pipeline Cutterhead Dredge



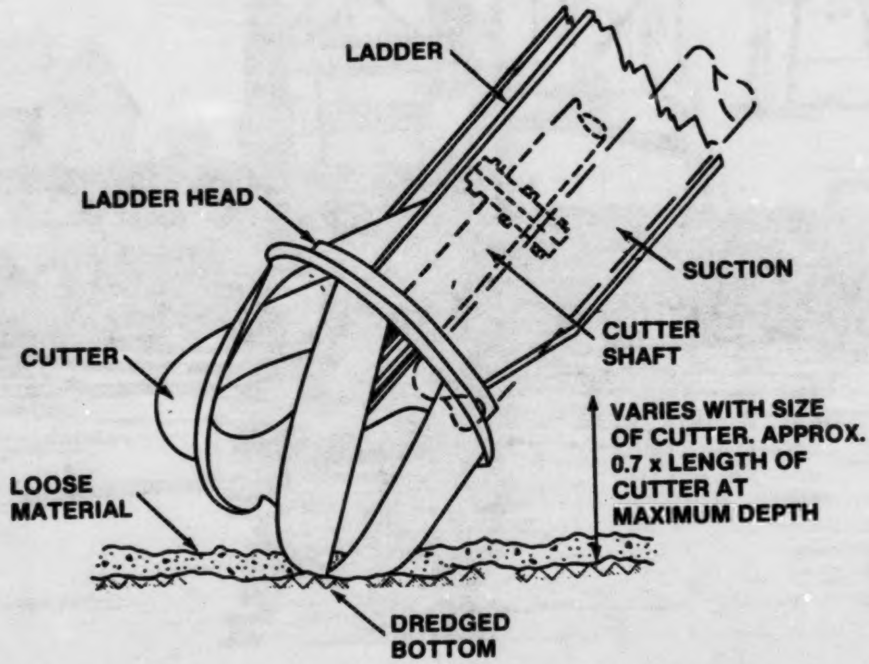
Photograph 2-1: Forward Components of a Pipeline Cutterhead Dredge



Photograph 2-2: Pipeline Cutterhead Dredge Spud Gantry



Photograph 2-3: Closed Nose Basket Cutter



LADDER
LADDER HEAD
SUCTION
CUTTER SHAFT
CUTTER
VARIES WITH SIZE OF CUTTER. APPROX. 0.7 x LENGTH OF CUTTER AT MAXIMUM DEPTH
LOOSE MATERIAL
DREDGED BOTTOM

Figure 2-2: Cross-Section View of Typical Cutterhead and Suction

TABLE 2-1

TYPICAL SPECIFICATIONS FOR FIVE SIZES OF PIPELINE DREDGES (HUSTON, et al., 1976)

Item	Size of Discharge Pipe, In Inches 12	16	20	24	28
Length, in feet	100	120	140	160	175
Beam, in feet	35	40	45	50	50
Depth, in feet	8	9	10	12	15
Displacement, in tons	560	840	1,200	1,850	3,000
Pump Power, in brake horsepower	570	1,000	1,500	2,700	5,000
Pump Speed, in revolutions per minute	500	400	350	325	300
Cutter Power, in brake horsepower	150	200	400	750	1,000
Cutter Speed, in revolutions per minute	5-30	5-30	5-30	5-30	5-30
Spud Length, in feet	55	60	70	90	100
Ladder Length, in feet	50	55	60	70	80
Maximum Pipeline, in feet	2,500	4,000	5,000	7,000	9,000
Maximum Width of Cut, in feet	160	200	220	270	325
Minimum Width of Cut, in feet	50	60	70	90	90
Maximum Digging Depth, in feet	35	40	45	50	60
Minimum Digging Depth, in feet	4	5	6	8	12

o Main Pump. The main dredge pump is located forward in the hull of the dredge at the lowest possible elevation. This low elevation reduces the distance the dredge must lift the slurry under vacuum conditions. The dredge pump has a height of approximately four times the discharge pipe diameter and a vaned impeller rotating between 250 r.p.m.'s (for small dredges) to 900 r.p.m.'s (for large dredges). The rotating vaned impeller centrifugally forces the dredged slurry to the outer circumference of the dredge pump shell where it enters the discharge line at pressures of 50 to 300 pounds per square inch (psi).

b. Description of Operation. The cutterhead dredge is generally equipped with two stern spuds that hold the dredge in working position and help to advance the dredge into the cut or excavating area. During operation, the cutterhead dredge swings alternately from side to side using the port and starboard as a pivot (figure 2-3). Cables attached to anchors on each side of the dredge control lateral movement.

Excavated material is pumped through the discharge pipe to the disposal site. Open-water disposal requires only a floating discharge pipeline made up of

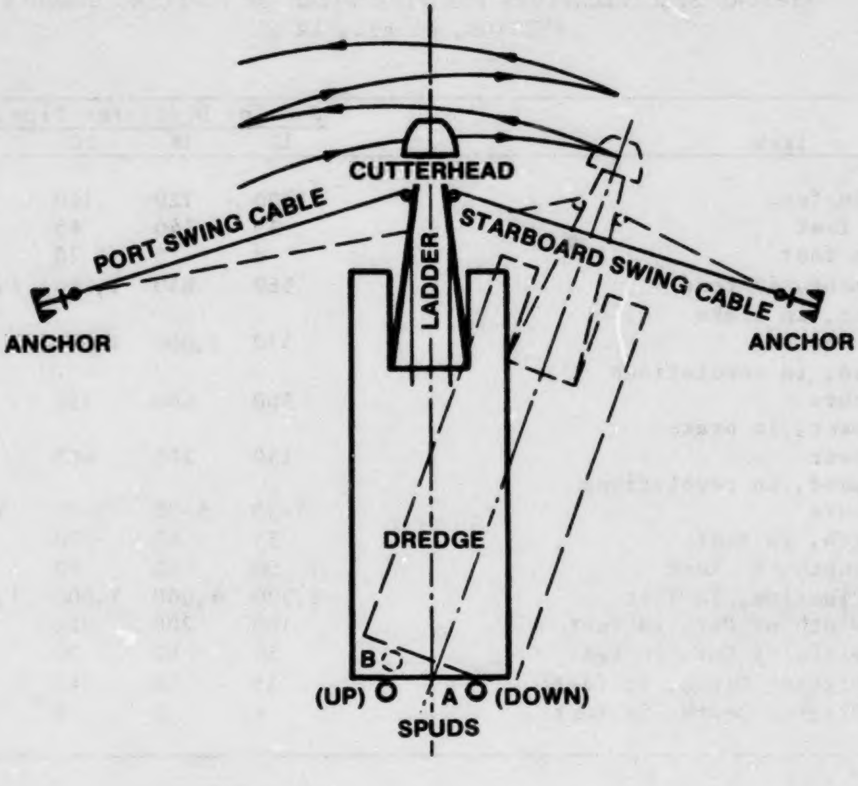


Figure 2-3: Operation of Cutterhead Dredge — Plan View

sections of pipe mounted on pontoons and held in place by anchors. Additional sections of shore pipeline are required when upland disposal is used. The excavated materials may be placed in hopper barges for disposal in open water or in confined areas that are remote from the dredging site. Depending on the size of the dredge and the physical character of the material, pipeline transport distances can range up to about 2 miles. Transportation beyond that point usually requires another pump to "boost" the slurry along. Distances less than 2 miles may require booster pumps for coarse sediments, with small dredges, and to dispose in sites that are elevated in relation to the dredge (1 foot of vertical discharge pumping is approximately equal to 200 feet of horizontal pumping distance).

c. Characteristics. Cutterhead dredges in pipeline diameters from 8 inches through 27 inches are readily available in the Pacific Northwest. Table 2-2 shows specifications for typical cutterhead dredges. The minimum depth of single pass excavation would be approximately the same as one-half the pipeline diameter. Production (Prod.) for minimum depth pass excavation can be calculated from the table as follows:

$$\text{Prod. (Min. Pass)} = \frac{\text{(1/2 x Discharge Diameter)}}{\text{(Maximum Depth Pass Excavation)}} \text{ x Prod. (Max. Pass)}$$

Actual vertical precision of the cut is often limited by the mechanical control of the ladder and suction head to approximately 1 foot.

d. Equipment and Operational Considerations. Cutterhead dredges can excavate all anticipated Commencement Bay materials (except where old piers and piling may be encountered) and pump the dredged materials through pipelines to an upland, nearshore, or open-water disposal site without rehandling. This mimimizes handling of, and exposure to, contaminated dredged material.

Most available cutterhead dredges have limited capacity for dredging deeper than 50 feet below water level. Dredge ladder modifications would be required to dredge in deeper water. Conventional cutterhead dredges are not self propelled but require towboats to move them between dredging locations. Thus, mobilization and set up are major and costly undertakings.

e. Operational Controls. There are a number of operator and operational controls for pipeline cutterhead dredges that can be considered when dredging contaminated sediments. These controls serve the primary purpose of reducing sediment resuspension during dredging. Many of these controls are well founded in field observations of dredging but have not been subjected to verification or quantitative testing.

Because the cutterhead dredge was developed to loosen densely packed deposits and cut through soft rock, it can excavate a wide range of materials. The cutterhead, however, may not be needed to remove soft, free-flowing sediments. Rotation of the cutterhead produces a turbidity cloud that may escape from the dredge. Common practice is to use the cutterhead whether it is

TABLE 2-2

SPECIFICATIONS FOR TYPICAL CUTTERHEAD DREDGES WORKING IN COMMENCEMENT BAY

Dredge Type	Pipeline Diameter Pipeline	Dredge Pumps			Production Rate C.Y./HR	Maximum Dredging Depth FT	Maximum Depth of Single Pass Excavation IN
		H.P.	Size	Drive			
Cutterhead	6	175	8	Diesel	71	12	18
Cutterhead	8	175	8	Diesel	79	12	18
Cutterhead	10	335	12	Diesel	225	25	18
Cutterhead	12	520	14	Diesel	405	25	18
Cutterhead	14	520	16	Diesel	525	25	21
Cutterhead	16	1,125	18	Diesel	656	40	21
Cutterhead	20	1,700	24	Diesel	1,024	50	24
Cutterhead	24	2,250	24	Diesel	1,211	50	30
Cutterhead	30	3,600	30	Diesel	1,875	50	36

needed or not, for debris control and because of the effort needed to remove it. With the cutterhead removed, the cutterhead dredge becomes, in effect, a plain suction dredge with reduced turbidity during dredging. It could remove the softer shoaled materials such as those found in inner Sitcum Waterway and leave the hard packed, native materials below. This would be especially useful when the softer surface materials contain the majority of the contaminants. If the cutterhead is required for effective operation, turbidity caused by conventional cutterhead dredging can be reduced by controlling the cutter r.p.m.'s and swing speed. Since optimum r.p.m.'s and swing speed will vary with each dredge and type of material, experimentation will be required.

Large sets and very thick cuts should be avoided since they tend to bury the cutterhead and may cause increased resuspension if the suction cannot pick up all of the dislodged material.

The leverman should step the dredge forward so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts; these windrows tend to slough into the cuts and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a walking spud system (see dredge modifications below).

Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope, resuspending sediment as it falls. The specified slope should be cut by making a series of smaller boxes. This method, called "stepping" the slope, will not eliminate all sloughing but will help to reduce it.

On some dredging projects, it is more economical to roughly cut and remove most of the material, leaving a relatively thin and irregular layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by ambient currents or prop wash from passing ship traffic. Requiring complete removal on each pass will reduce this resuspension.

Loss of volatile contaminants during hydraulic pipeline transport and discharge of slurried dredged material could be partially prevented by reducing air space in the pipeline and by submerging the pipe end in the disposal site pond. Reducing the air space would result in a loss of pumping efficiency due to over pumping the slurry. The submerged pipeline would require constant moving to ensure sediment dispersion within the site. This technique is likely only applicable to fine-grained materials. Neither of these techniques has been field tested.

f. Dredge Modifications. Recent modifications to pipeline dredges have improved their production capabilities and reduced dredging sediment resuspension. Greater production rates are achieved by pumping a higher solids concentration which reduces the quantity of return water which may be contaminated and require treatment. Recent modifications considered here include walking spuds, ladder pumps, flow and density instrumentation, and underwater video and sensor equipment.

A recent improvement in cutterhead pipeline dredges is the addition of the walking spud. This is a hydraulic ram connected on a horizontal platform to the spud gantry which can advance the dredge up to 40 feet without taking a step (figure 2-4). Using the walking spud, the dredge does not have to stop pumping sediments to move forward. Lost pumping time or increased pumping of water during dredge stepping is eliminated. Walking spuds are common on European dredges; however, few dredges have them in the United States; none are located in the Pacific Northwest.

Photograph 2-1 shows an additional pump located on the ladder of the dredge. Called a ladder pump, this pump is underwater during normal dredging operations and supplies the dredge slurry to the main pump under slight pressure. This allows the main pump to use all of its available power to transport dredged materials. It increases the percentage of solids pumped and dredge production.

The addition of flow gages and nuclear density gages provide the dredge operator with instant production data. This information can be used to make adjustments to optimize production, such as adjusting cut depth, cutter rotation, ladder swing, etc.

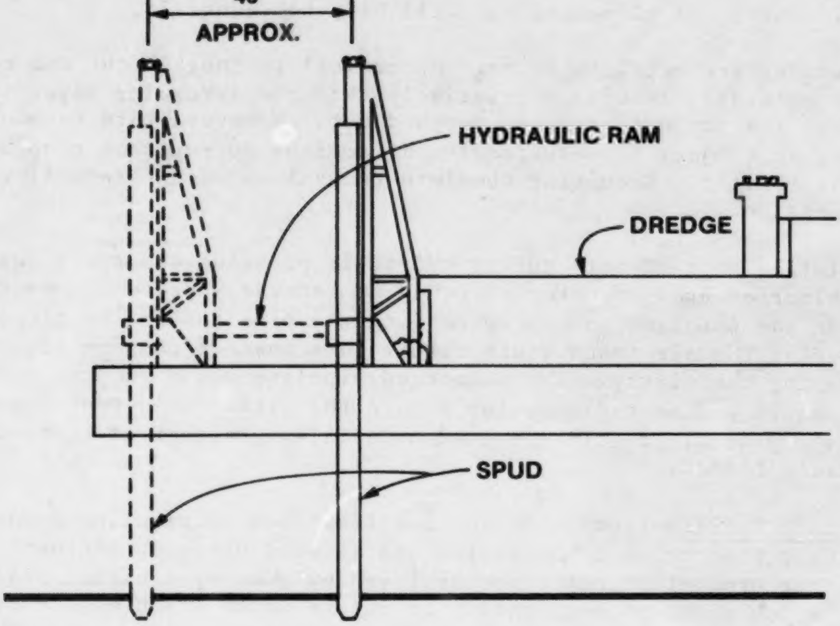


Figure 2-4: Walking Spud

Closed circuit underwater video camera's and water sensors can be mounted on the dredge ladder and used to monitor turbidity in vicinity of the cutterhead. Adjustments can be made in cutter rotation speed (r.p.m.'s) and swing speed to minimize resuspension of dredged materials. Video cameras are only effective when dredging in relatively clear waters. Sensors are best used in turbid waters.

Loss of volatile contaminants associated with gas present in the sediments in situ could be substantially reduced by collecting and treating gas from dredge degasser systems. To date, the only known application of this was done by the Dutch. Gases were fed into the dredge furnace and discharged with engine emissions; water and sediment obtained from the degasser was injected into the discharge pipeline. Gas quantities collected and contaminant incineration efficiencies were not monitored. Collection of materials from the degasser system also avoids the sediment resuspension resulting from degasser systems that commonly discharge into the water column.

Loss of volatile contaminants during discharge could be partially reduced by placing a shroud over the discharge opening in order to collect the volatiles. This idea has not been developed or field tested.

2.02.02. Suction and Dustpan Dredges.

a. Description of Equipment. Both suction and dustpan dredges are conventional pipeline dredges with modified dredging heads. They have many similarities and are only briefly discussed below.

The suction dredge is a pipeline cutterhead dredge with the cutterhead removed (figure 2-5). Many times skid plates under the ladder and a vertical elbow on the suction are added to improve operations.

The dustpan dredge is a hydraulic suction dredge that uses a widely flared dredging head along which are mounted pressure water jets (figure 2-6). The jets loosen and agitate the sediments which are then captured in the dustpan head as the dredge itself is winched forward into the excavation. This type of dredge was developed by the Corps of Engineers to maintain navigation channels in uncontrolled rivers with bedloads consisting primarily of sand and gravel (e.g., Mississippi River).

b. Description of Operation. The operation of the suction dredge is the same as that of the cutterhead pipeline dredge (paragraph 2.02.01(b) above). The dustpan dredge moves by winching itself forward to anchors set upstream of the dredging area. The dustpan dredge maintains navigation channels by making a series of parallel cuts through the shoal areas until the required widths and depths are achieved.

c. Characteristics. The production rates and dredging depths for the suction and dustpan dredge are comparable to those for cutterhead pipeline dredges shown in tables 2-1 and 2-2. One difference to note is that the dustpan dredge can excavate very thick cuts (up to 6 feet) on a single pass.

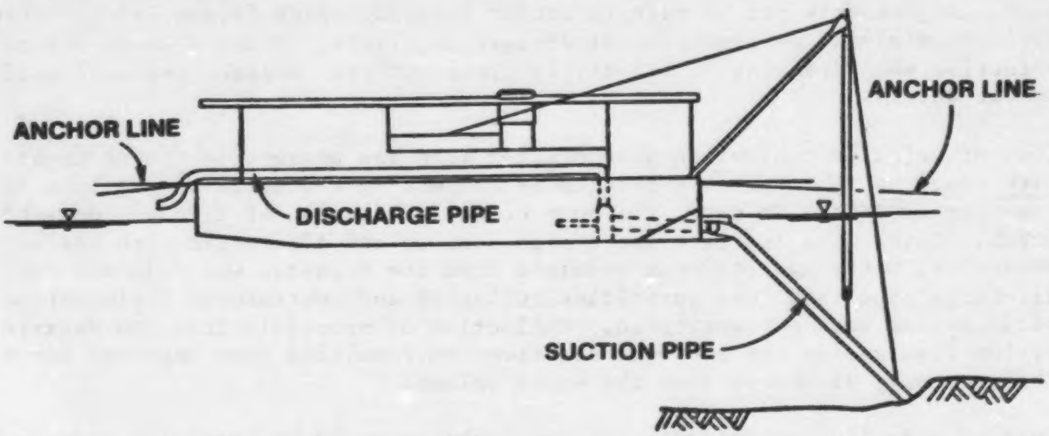


Figure 2-5: Plain Suction Dredge

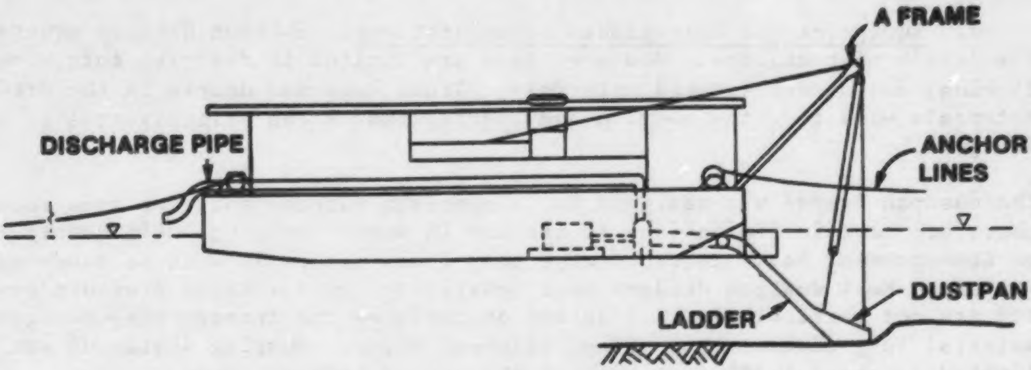


Figure 2-6: Dustpan Dredge

Dustpan dredges are: (1) all in the large dredge class with 30-inch pipelines or larger, (2) all located on the Mississippi River or its tributaries, and (3) all (with one exception) operated by the Corps of Engineers.

d. Equipment and Operational Considerations. Suction dredges generate low levels of turbidity. However, they are limited to dredging soft, free flowing, and unconsolidated materials. Trash logs and debris in the dredge materials will clog the suction and greatly reduce the effectiveness of the dredge.

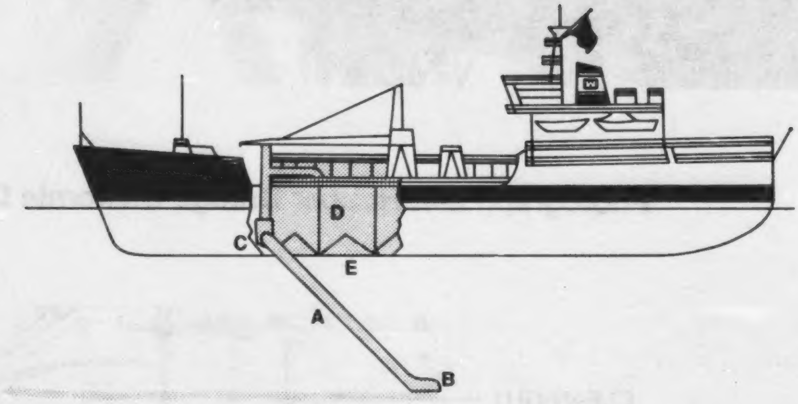
The dustpan dredge was designed for a specific purpose and, for this reason, there are certain limitations to its use in other dredging environments such as Commencement Bay. It can dredge only loose materials such as sands and gravels. Most dustpan dredges have relatively low discharge pressure pumps and are not particularly well suited or designed for transporting dredged material long distances to upland disposal sites. Pumping distances are limited to about 1,000 feet without the use of booster pumps.

e. Operational Control and Dredge Modifications. With the exception of cutterhead controls, applicable operational controls for a suction dredge are similar to those for a cutterhead dredge (see paragraph 2.02.01.e.). For dustpan dredges, the angle of the water jets on the head and the water pressure from these jets can and should be adjusted to achieve the minimum amount of sediment resuspension.

2.02.03 Hopper Dredges.

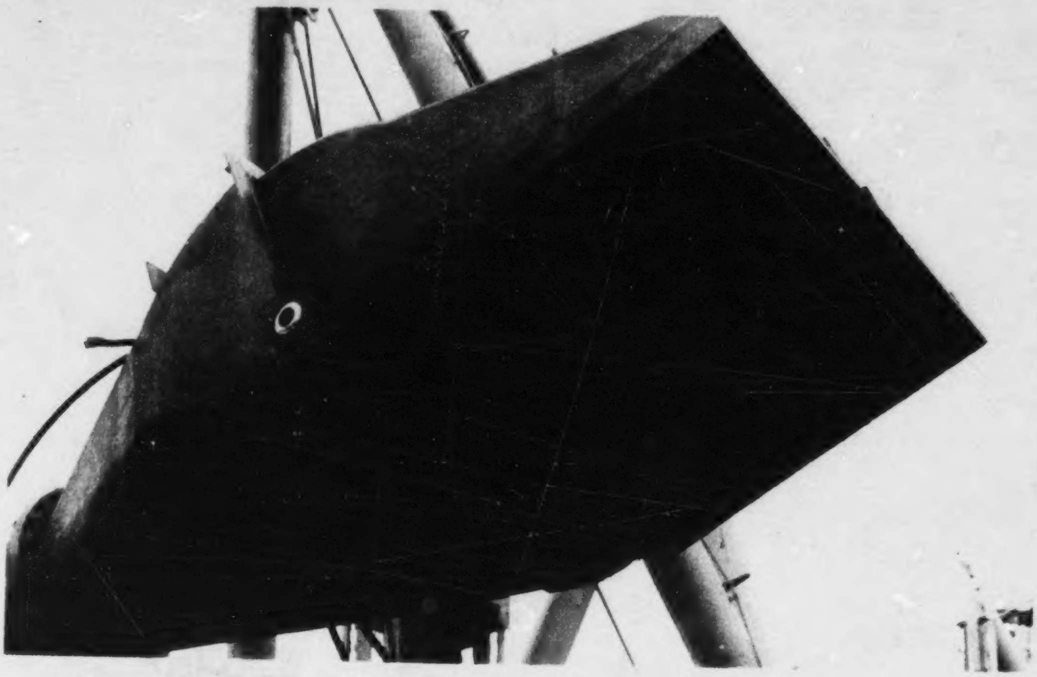
a. Description of Equipment. Hopper dredges are self-propelled, seagoing ships from 180 to 550 feet in length with either barge-type hulls or molded hulls with the lines of ocean vessels (figure 2-7). They are equipped with propulsion machinery, sediment containers called hoppers, dredge pumps, and other special equipment. Dredged materials are raised by large centrifugal pumps through drag pipes connected to dragheads that are in contact with the channel bottom (figure 2-8 and photograph 2-4). Dredged materials are then discharged into the hoppers. Hopper dredges are classified according to hopper capacity: large class hopper dredges have hopper capacities of 6,000 cubic yards (c.y.) or greater, medium class hopper dredges have hopper capacities of 2,000 to 6,000 c.y., and small class hopper dredges have hopper capacities of 500 to less than 2,000 c.y. Presently located in the Pacific Northwest are medium and small class hopper dredges. They are equipped with twin propellers, twin rudders, and bow thrusters to provide required maneuverability. Track plotting surveying equipment can be placed aboard for exact positioning of the dredge.

b. Description of Operation. The operation of a hopper dredge in Commencement Bay would involve greater effort than that required for the ordinary handling of an ocean cargo vessel, which is usually attached to a tug and navigating the centerline. The dredge will usually operate near the edge of the channel using its own power to stay in the dredging area. Dredging is accomplished by repetitive passes over the area to be dredged, each pass removing inches of surface material. During dredging operations, hopper



Dragarms (A) with dragheads (B) extend from each side of the ship's hull. The dragheads are lowered to the channel bottom and slowly pulled over the area to be dredged. Pumps (C) create suction in the dragarm and the silt or sand is drawn up through the arms and deposited in hopper bins (D) in the vessel's midsection. When the bins are full, the dredge sails to the designated disposal area and empties the dredged material through large hopper doors (E) in the bottom of the hull.

FIGURE 2-7: TYPICAL HOPPER DREDGE COMPONENTS



Photograph 2-4: Hopper Dredge California Draghead

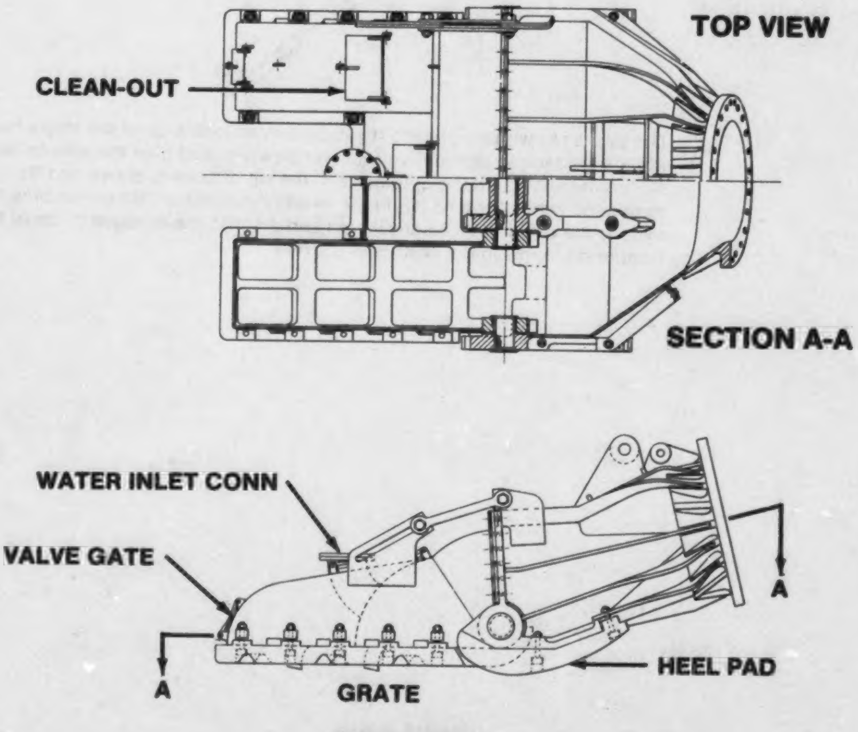


Figure 2-8: Hopper Dredge California Draghead

dredges travel at a ground speed of 2 to 3 miles per hour and can dredge in depths of about 10 to 60 feet. The draghead is moved along the channel bottom as the vessel moves forward. The dredged material is sucked up through the drag pipe and deposited in the hoppers of the vessel where it settles. As the hopper is filled, overflow water is usually discharged at the site of dredging. Once loaded, hopper dredges cease dredging and move to the disposal site to unload. The hopper is considered to be full once an economic load has been achieved. The economic load is based on the pumping time required to obtain the least cost per c.y. of solids dredged and discharged. It considers pumping and nonpumping times (travel to disposal site and back) of the entire dredging cycle and considers only solids (suspended and settleable) that make it to the disposal site (not overflow loss). Usually the economic load, which will vary by equipment, disposal site location, and sediment characteristics, is specified as a maximum overflow pumping time that allows the greatest possible amount of dredged material to settle in the hopper. For some exclusively fine-grained materials which may remain in a slurry, the economic load may not require overflow pumping.

c. Characteristics. Hopper dredge characteristics are extremely variable. Hopper sizes vary from 500 to 8,000 c.y., and pumping rates per minute from 15 to 150 c.y. Minimum dredging depth is limited by the draft of the dredge, from 12 to 28 feet, and maximum dredging depth varies from 45 feet to 80 feet.

d. Equipment and Operational Considerations. Hopper dredges can be used to transport dredged materials greater distances than pipeline dredges. Hopper dredges, though not precise in dredging location (horizontal accuracy often cannot be controlled to less than a 10-foot tolerance), can remove a few inches of contaminated materials from the bottom with each pass. They can dredge shoals that slope or vary in elevation. Few other types of dredges are capable of doing this. However, the hopper dredge cannot dredge effectively along piers or near structures. Hopper dredges are often the most economical type of dredge to use where disposal areas are not available within economical pumping distances of hydraulic pipeline dredges. The hopper dredge provides self-contained storage of dredged material which eliminates the need for separate barge, scow, or pipeline.

As discussed for pipeline dredges above, modification of hopper dredges to collect gases from the degasser system and shrouding of the hopper bin to capture gases discharged from the pipe are potential dredge modifications that could be used to reduce loss of volatile contaminants during dredging. These modifications have not been attempted to date.

The hopper dredge can be mobilized and initiate dredging in a relatively short period of time. Hopper dredges have excellent maneuverability and can work effectively in congested harbors such as Commencement Bay.

e. Operational Control. The hopper dredging of contaminated materials may be restricted by pumping or loading the hopper bins with dredge slurry and not allowing overflow. This would result in a load that would be approximately 80 percent water and 20 percent sediments for silty sands found in

Commencement Bay. This compares to an average of 70 percent sediment using an economic load. The rate of solids loss in the overflow (which may determine if overflow is acceptable) will vary with amount of water in the hopper, hopper capacity and drainage characteristics, material characteristics (settleability), pumping rate, and elapsed time of overflow.

2.02.04 Special-Purpose Dredges. Special-purpose dredging systems have been developed during the last few years in Japan, Europe, and the United States to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediments. Most of these systems are not intended for use on typical maintenance operations; however, they do provide alternative methods for dredging projects involving contaminated sediments that require more careful handling. The special-purpose dredges that appear to have the most potential in limiting resuspension are shown table 2-3, taken from Herbich and Brahme (in press). A description of each dredge follows.

a. Mudcat Dredge. The mudcat is a small, hydraulic dredge designed to remove mulch, weeds, sand, municipal sludge, and industrial wastes. Dredging depth is limited to 15 feet or less. It is portable and designed for projects where a production of 50 to 130 c.y./hour at up to 30 percent solids is sufficient. Instead of a conventional cutter, the mudcat has a horizontal cutterhead equipped with cutter knives and a spiral auger that cuts the sediment and moves it laterally towards the center of the auger where it is picked up by the suction (figure 2-9). It can remove sediments in an 8-foot width with a depth of cut of up to 15 feet. The mudcat leaves the bottom flat and free of the windrows that can be pushed up between swings in cutterhead dredging operation. A retractable shield shrouds the cutterhead, entraps suspended material, and minimizes turbidity (Herbich and Brahme, in press).

During monitoring, Herbich and Brahme (in press) report that near bottom suspended solids concentrations 5 feet from the auger were slightly greater than 1,000 mg/l relative to the background concentration of 500 mg/l. Surface and middepth concentrations measured 5 feet and 10 feet in front of the auger were typically less than 200 mg/l compared to the background values of 40 to 65 mg/l. In general, the turbidity plume was confined to within 20 feet of the dredge. Studies at Vandalia Reservoir showed suspended solids concentrations of between 100 and 300 mg/l at the auger (Barnard, 1978).

Mudcat dredges are available on the Pacific Coast. They are compact and readily transportable by truck or air and can be operated in confined and isolated areas with shallow waters. However, the limited dredging depth (less than 15 feet) constrains its use to intertidal areas or low tide periods in Commencement Bay.

b. Pneuma Pump. The pneuma system was the first dredging system to use compressed air instead of centrifugal motion to pump slurry through a pipeline. It has been used extensively in Europe and Japan. According to the literature published by the manufacturer, this system can pump slurry at a relatively high solids content with little generation of turbidity. The operation principle is illustrated in figure 2-10. During the dredging process, the pump is submerged and sediment and water are forced into one of the empty cylinders through an inlet valve. After the cylinder is filled,

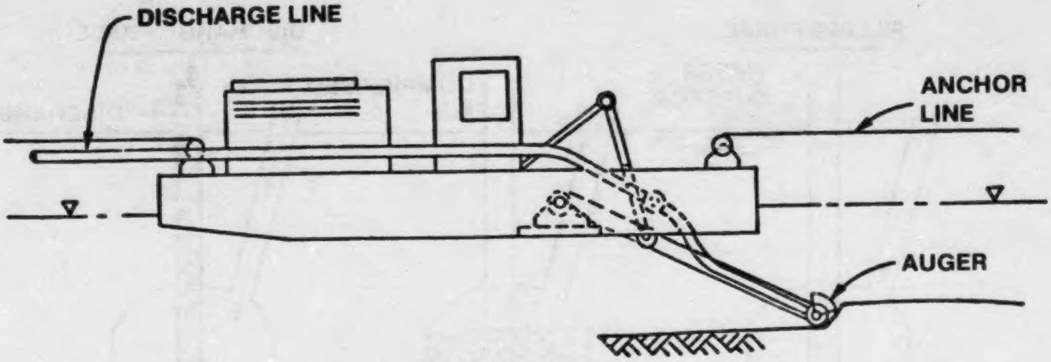


Figure 2-9: Mudcat Dredge

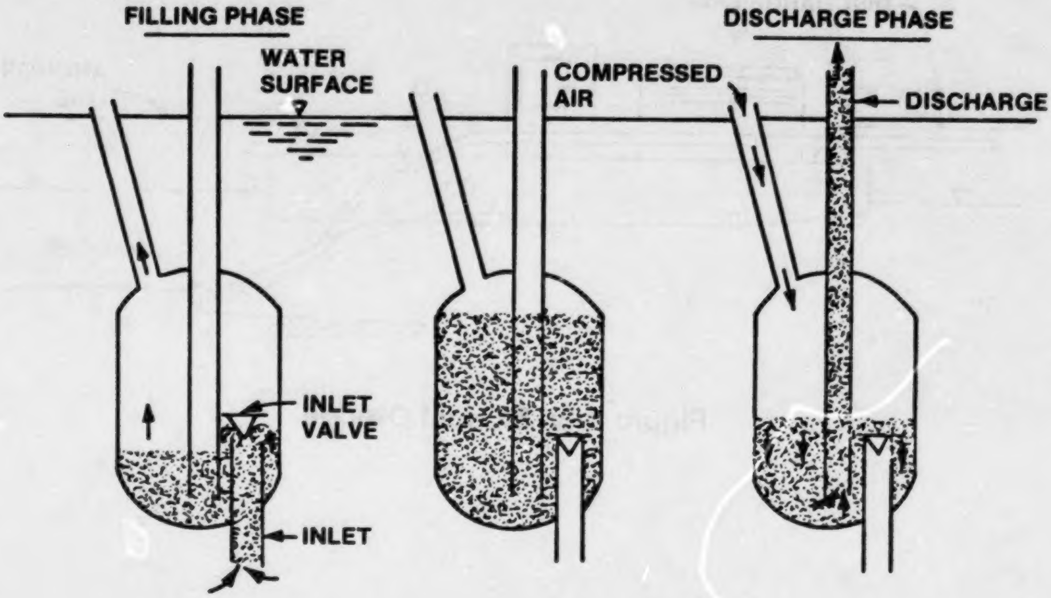


Figure 2-10: Operating Cycle of the Pneuma Pump

TABLE 2-3

SUSPENDED SEDIMENT LEVELS PRODUCED BY VARIOUS SPECIAL-PURPOSE DREDGES

Name of Dredge	Suspended Sediment Level
Mudcat Dredge	5 feet from auger, 1000 mg/l near bottom (background level 500 mg/l)
	5 to 12 feet in front of auger, 200 mg/l surface and middepth (background level 40 to 65 mg/l)
Pneuma Pump	48 mg/l 3 feet above bottom
	4 mg/l 23 feet above bottom (16 feet in front of pump)
Cleanup System	1.1 to 7.0 mg/l above suction
	1.7 to 3.5 mg/l at surface
Oozer Pump	6 mg/l (background level) 10 feet from head
Refresher System	4 to 23 mg/l at 10 feet from head

compressed air is supplied to the cylinder, forcing the water out through an outlet valve. When the cylinder is almost empty, air is released to the atmosphere, producing atmospheric pressure in the cylinder. The pressure difference between the inside and outside of the cylinder creates a suction that forces sediment into the cylinder. When the cylinder is filled with sediment, compressed air is again pumped into the cylinder to expel the sediment from the cylinder. The capacity of a large plant (type 1500/200) is 2,600 c.y./hour. The system has been used in water depths of 150 feet; however, 500 feet depths are theoretically possible.

Field tests on a pneuma model 600/100 were conducted by the WES of the U.S. Army Corps of Engineers (Richardson, et al., 1982). The results of turbidity monitoring, although not definitive, seemed to support the manufacturer's claim that the pneuma pump generates a low level of turbidity when operated in loosely consolidated, fine-grained sediments. It was also found that the pneuma pump was able to dredge at almost _in situ_ density in a loosely compacted silty clay typical of many estuarine sediments. The pneuma system was used successfully in PCB cleanup operations on the Duwamish Waterway in Seattle, Washington, in 1976. The pneuma pump, however, was not able to dredge sand at _in situ_ density. The only pneuma-type dredge available in the United States at this time is operated by Namtex Corporation of Chicago, Illinois. The pneuma system is crane supported and thus can be operated in confined areas using various structural mounts. It dismantles easily for truck or air transport and can be operated in most water depths. Cables and pipelines used for the system will create temporary obstructions to navigation.

c. Oozer Dredge. The oozer dredge system was developed by Toyo Construction Company, Japan. The dredge operates in a manner similar to the pneuma pump system; however, there are two cylinders (instead of three) and a vacuum is applied during the cylinder filling stage to achieve more rapid filling of the cylinders. The dredge system is usually mounted on a ladder and is equipped with special suction and cutterheads depending on the type of material being dredged. Dredging depth is limited only by the depth the ladder can reach. Dredging conditions, such as the thickness of sediment being dredged, bottom elevation after dredging, and amount of resuspension, are monitored by high frequency, acoustic sensors and an underwater television camera. A large oozer dredge has a dredging capacity ranging from 400 to 650 c.y./hour, producing a slurry of up to 80 percent of *in situ* sediment density. During one dredging operation, suspended solids levels within 10 feet of the dredging head were all within background concentrations of less than 6 mg/l (Herbich and Brahme, in press).

d. Cleanup System. To avoid resuspension of sediment, Toa Harbor Works of Japan developed the unique cleanup system for dredging highly contaminated sediment (Sato, 1976). The cleanup head consists of a shielded auger on the front end of a pipeline dredge. The head collects sediment as the dredge swings back and forth and the shield guides the sediment towards the suction of a submerged centrifugal pump (figure 2-11). To minimize sediment resuspension, the auger is shielded and a movable wing covers the sediment as it is being collected by the auger. The resulting slurry consists of 30 to 40 percent solids by weight. Sonar devices indicate the elevation of the bottom. An underwater television camera is used to show material being resuspended during a dredging operation. Suspended sediment concentrations around the cleanup system ranged from 1.7 to 3.3 mg/l at the sediment surface to 1.1 to 7.0 mg/l at 10 feet above the suction equipment, relative to the background near surface levels of less than 4.0 mg/l (Herbich and Brahme, in press).

e. Refresher System. Another dredging method designed recently by the Japanese is the refresher system. The refresher uses a helical-shaped gather head to feed the sediments into the suction with a cover over the head to reduce resuspension (see figure 2-12). The refresher also uses an articulated dredge ladder to keep the head level to the bottom over a wide range of dredging depths. During several comparison tests in similar material, the refresher system produced suspended sediment levels of from 4 to 23 mg/l within 10 feet of the dredge head as compared to 200 mg/l with a conventional cutterhead dredge. Production for the cutterhead (26-inch discharge) was 800 c.y./hour, while production with the refresher system (17-inch discharge) was 350 c.y./hour. The researchers felt that the refresher system produced one-fifteenth of the total resuspension produced by the operation of a cutterhead dredge (Kaneko et al, in press).

f. Availability of Cleanup, Oozer, and Refresher Dredges. The cleanup, oozer, and refresher dredges are all Japanese-manufactured equipment. The oozer pump is not presently well known or available to United States markets, and its use would likely require a specific international, Goverment, or private agreement. The cleanup and refresher dredges, modifications to the ladder and head of pipeline dredges, may be available and marketed in the

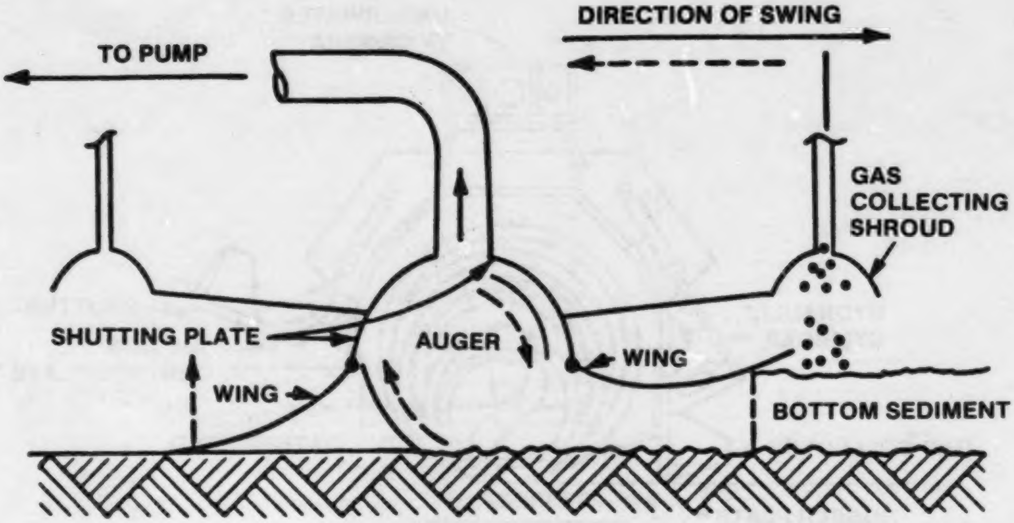
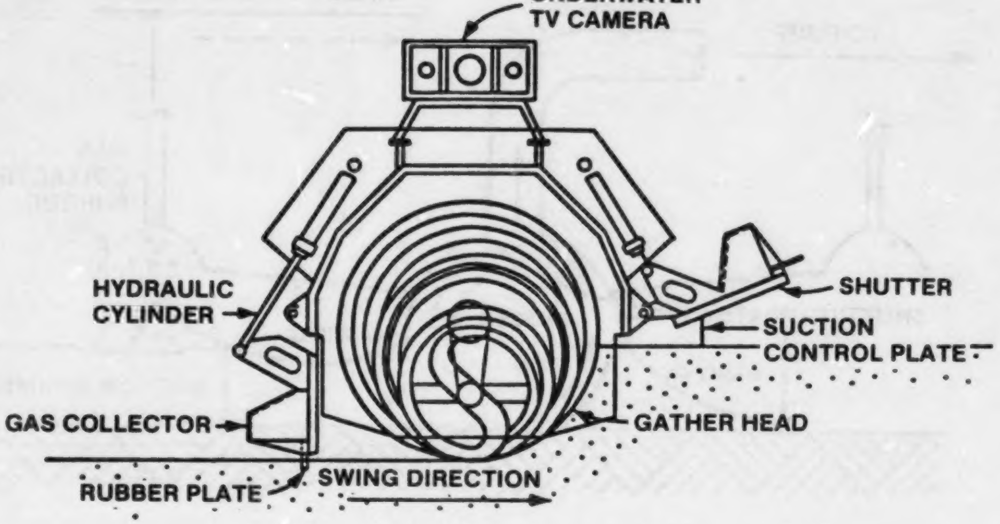
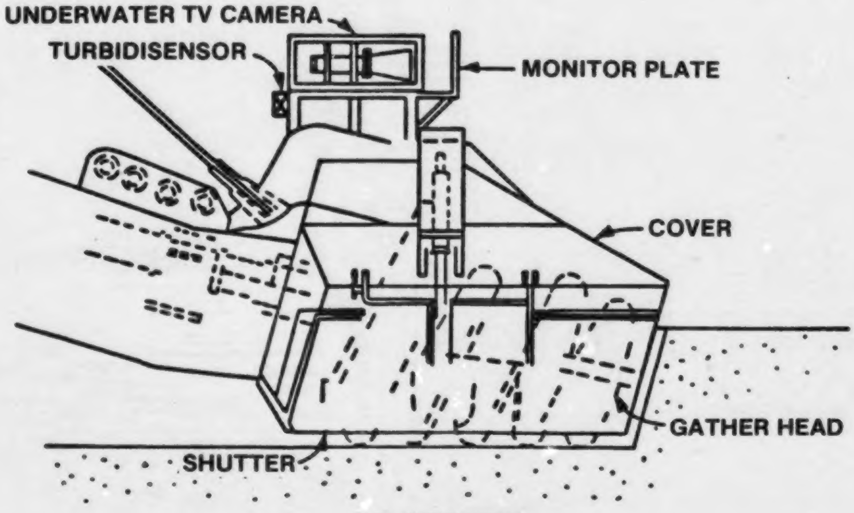


Figure 2-11: Clean-Up System Dredgehead



A. FRONT VIEW



B. SIDE VIEW

Figure 2-12: Refresher System

United States in the near future. However, as with most special-purpose dredges, additional research, development, and experience are needed to fully determine their application and limitations.

2.03 Mechanical Dredges. Mechanical dredges are characterized by the use of some form of bucket to excavate and elevate the bottom materials. They do not transport the material to the ultimate deposition area except in the infrequent instances where the material can be deposited on the bank or behind a dike or seawall immediately adjacent to a narrow waterway. Normally the mechanical dredge releases materials into a barge, which then transports the material to the disposal site.

Mechanical dredges can be categorized into three subgroups as a function of how their buckets are connected to the dredge: wire rope connected, structurally connected, and chain and structurally connected.

Examples of wire rope mechanical dredges are the clamshell, dragline, and orange-peel dredges. These dredges are frequently called simply "bucket" dredges. Examples of structurally connected mechanical dredges are the power shovel and the backhoe dredges. The only example of the third subgroup is the bucket ladder or bucket line dredge which dredges continuously using multiple buckets mounted on an endless chain. This report will address only bucket dredges; other mechanical dredges were discussed in section 2.01.03 above.

a. Description of Equipment. The bucket dredge is so named because it utilizes a bucket to excavate the materials to be dredged (figure 2-13). There are different types of buckets to accomplish various types of dredging and buckets can be changed to suit operational requirements. For this report, the term "bucket dredge" will refer primarily to the clamshell bucket. Buckets range in capacity from 1 to 18 c.y. and are attached to a crane by wire rope. The crane is pedestal mounted on a flat-bottom barge. In most cases, anchors and spuds are used to position and move the barge. By using the anchors alone, the vessel can work in water that is deeper than spud length. The effective working depth is limited to approximately 100 feet. Bucket dredges load dredged material into scows or barges that are towed to the disposal site.

b. Description of Operation. Most bucket dredges are not self propelled, but can move over a limited area during dredging by manipulating the spuds, anchors, and crane boom. After placing anchors and spuds the dredge drops the open bucket into the sediments. The jaws of the bucket are closed shearing material from the bottom, and the bucket is raised above the water surface and swung over the barge where the sediment is released. As the bottom of the waterway is dredged to the desired depth, the dredge is moved forward.

c. Characteristics. The bucket dredge typically operates at speeds of 30 to 60 buckets per hour. Larger buckets generally resuspend less material per c.y. removed and are more cost effective. Because of this, only medium and large bucket sizes were considered for possible use in Commencement Bay.

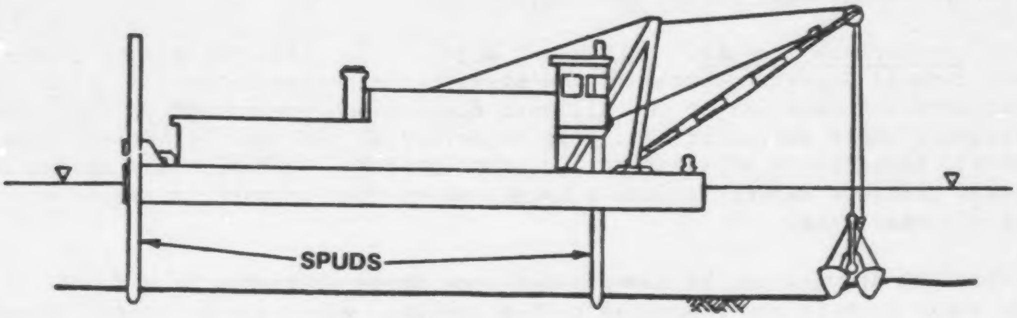


Figure 2-13: Bucket Dredge

d. Equipment and Operational Considerations. The advantage of bucket dredges over hydraulic dredges is that they move sediments with minimum addition of water. They should be considered for use where sediment contamination is highly water soluble. Bucket dredges dredge slopes and varied contour elevations to approximately 2-foot vertical tolerance, less accurate than most hydraulic dredge types. However, vertical accuracy could be increased by lowering the bucket to a specified depth and then closing rather than dropping the full weight of the bucket. This practice is not often used because it substantially reduces production rate, increases transport of water (in the bucket), and reduces area of each grab (as jaws may impact bottom in a partially closed position). This technique may be appropriate for highly contaminated and/or unconsolidated materials located immediately on the surface. Other considerations are listed below.

o Large bucket dredges can dredge materials from above water level to depths of over 100 feet.

o Large bucket dredges of all sizes are readily available in Puget Sound and the Pacific Northwest.

o Scows or barges are required to move the dredged material to the disposal site. Mechanical or hydraulic rehandling of the dredged material is required if the material is to be placed on an upland site.

o Bucket dredges can maneuver and operate in confined areas and are capable of working in debris and around obstruction.

o Bucket dredges excavate materials at in situ density, resulting in lower volumes of material to handle (no hydraulic swell factor).

e. Operational Control and Modification. Operators of bucket dredges should overlap grabs in lieu of the conventional practice of sweeping the bottom to level out remaining humps. This may increase cost by up to 30 percent.

In soft, unconsolidated and contaminated surface sediments, the conventional practice of providing navigable water depth by dropping and penetrating through the soft surface layer, removing firmer subsurface materials, and allowing surface materials to slough into a hole will result in a low contaminant removal efficiency and high resuspension of contaminated sediments. Bucket weight should be adjusted to the density of surface sediments instead.

f. Dredge Modifications. On a c.y. basis, resuspension of dredged materials can be reduced by use of large buckets. Heavy weight, pick-tooth buckets are used to dredge hardpacked sediments; lighter weight buckets without teeth, called rehandling buckets, are utilized to dredge softer sediments. By selection of weight of buckets, the depth of cut can be controlled.

To minimize the turbidity generated by a clamshell operation, watertight buckets have been developed. The edges seal (tongue-in-groove arrangement) when the bucket is closed and the top is covered to minimize the loss of dredged material. Available sizes range from 1.3 to 18 c.y. These buckets are best adapted for dredging fine grained material. Corps of Engineers test comparisons of 1.3 c.y. typical clamshell and watertight clamshell indicate that the watertight buckets generate 30 to 70 percent less turbidity in the water column than typical buckets because leakage of the dredged material is reduced by approximately 35 percent. Existing clamshell buckets can be converted to watertight buckets by minor structural modifications.

2.04 Contaminant Efficiency of Dredging Methods. Chemical constituents associated with sediments are unequally distributed among different chemical forms and sediment phases depending on the physical-chemical conditions in the sediments and the overlying water. When contaminants introduced into the water column become fixed into the underlying sediments, they rarely if ever become part of the geological mineral structure of the sediment. Instead, these contaminants remain dissolved in the sediment interstitial water (pore water), become sorbed to the sediment ion exchange portion as ionized constituents, form organic complexes, and/or become involved in complex sediment oxidation-reduction reactions and precipitations. Dredging of contaminated sediments causes short-term loss of contaminants from gas, interstitial water, or solid phases. Dredging method also influences long-term contaminant losses at the disposal site.

2.04.01 Volatile Phase Contaminants.

a. General. There are several pathways whereby volatile contaminants find their way through water into the sediments. The most likely pathways are:

(1) groundwater seeps;

(2) bound to particulates in industrial and municipal effluents, these sinking to the bottom; and

(3) spills of concentrated contaminant that are heavier than water.

These processes can produce significant concentrations of volatile contaminants in aquatic sediments. In recent years, methods for sampling, storing, and analyzing sediments did not allow identificaton or proper quantification of many of these volatile compounds in the sediments.

Key factors influencing volatile contaminants loss during dredging are:

- the volume of gas present in the sediments in situ;

- the partitioning of contaminants between particulate, water, and gas phases of the sediment;

- the degree of disturbance and agitation of the sediments produced by dredging;

- the surface area of the sediments exposed to air during dredging; and
- the exposure time of sediments to air during dredging.

Contaminants will vary in how they distribute themselves between sediment phases; however, in general, contaminants with higher mobility rankings will be found in higher concentrations in the gas phase of the sediment than those with lower ranking (see appendix 1). The amount of gas in the sediments is not well documented and represents a key information need in making quantitative predictions of volatiles loss during dredging.

Hydraulic and mechanical dredging differ in several ways in the degree of sediment disturbance, the exposure time to air, and the surface area exposed. These are discussed below and provide the basis for evaluating performance of these dredging techniques.

b. Hydraulic Dredging. Hydraulic dredging moves sediments in a water slurry. This process represents a greater disturbance of the sediments than mechanical dredging and, therefore, results in greater loss of *in situ* gas and associated volatile contaminants. As a result, most hydraulic dredges (pipeline and hopper) have degassing systems to remove gas from the intake pipe prior to the main pump. The gas, which causes cavitation and wear of pump impellers, is discharged, along with a small amount of water and sediment into the water column or atmosphere. This degassing system provides the greatest potential loss of volatiles during the dredging process.

During transport of the slurry in the discharge pipe, some air is entrained from the small air space in the pipe. This air space and entrained air, which increase towards the discharge end of the pipe, allow additional loss of volatile contaminants. Upon discharge in an upland or nearshore site, air from the air space is lost to the atmosphere. In hopper dredges, the loss of volatiles occurs as the sediment slurry is discharged into the bin.

For pipeline dredging, the slurry may lose additional volatiles upon impact with the settling pond. The sudden reduction in pressure from *in situ* conditions before and after impact may increase the loss. After impact, volatile contaminants may be lost as the slurry runs out over a delta of dredged sediment. This shallow water and turbulent flow distribution of the slurry favors desorption and loss of contaminants as the surface area to volume ratio would be maximized at this point.

However, the dredging and transport process for hydraulically dredged sediments provide relatively brief exposure time to air. Over time, the processes governing equilibruim partitioning of contaminants in the sediments *in situ* will potentially concentrate volatiles in the available gas phase. Once *in situ* gas has been lost during dredging, there would be little opportunity for additional, substantial loss of volatiles in the disposed material. Overall, the loss of the most volatile contaminants found in the sediments is likely not to exceed 10 to 20 percent (assuming a large *in situ* gas volume).

Techniques for reducing loss of volatiles during hydraulic dredging are mentioned above: collection and treatment of gas from degassing systems; elimination of air space in discharge pipe by less efficient, full-pipe pumping; shrouding the discharge end of the pipe or the hopper bin to collect volatile contaminants; and submerging the discharge end of the pipe. Of these, priority for research and field experience should focus on collection of gas from degassing systems.

c. Mechanical Dredging. Mechanical dredging causes substantially less disturbance to the sediments than does hydraulic dredging. Additionally, the surface area to volume ratio of the sediments that are stockpiled on a transport barge is relatively low. The time that sediments remain exposed to the air is usually longer than for most hydraulic dredging jobs; however, the low disturbance and low surface area exposure substantially override the effect of longer exposure time. As a result, loss of volatile contaminants is less for mechanical dredging than for hydraulic dredging.

2.04.02 Soluble Phase Contaminants.

a. General. As with volatile contaminants, contaminants with a higher mobility ranking can be expected to have a higher concentration in the sediment interstitial water than those with a lower ranking. Quantitative predictions of the amount of any particular contaminant to be found in solution could be estimated by use of the contaminant specific partitioning coefficients and the volumes of sediment and interstitial water present. Again, key factors in the loss of soluble contaminants during dredging are the degree of sediment disturbance and the exposure of the sediments to additional water. In addition, the efficiency of a dredge at removing the liquid phase of a sediment is critical to the amount of soluble contamination lost.

b. Hydraulic Dredging. In hydraulic dredging, the use of water to move sediments will extract and dilute the interstitial waters and will expose the sediments to additional water that can provide for release of soluble contaminants from particle surfaces. The amount of contaminant that goes into solution will depend on a number of factors, including the contaminant's mobility, the types and relative strengths of binding surfaces, and the chemical conditions in the dredging site and slurry water.

Because the hydraulic dredge is designed to pump water, its removal of the liquid phase of the sediments is highly efficient, resulting in relatively little loss of soluble contaminants at the dredging site when compared to mechanical dredging. However, this slurry becomes a large volume of effluent that may require treatment at the disposal end of the process (or may be lost in hopper dredge overflow). After removal of the effluent, hydraulically dredged sediments typically produce greater quantities of water during dewatering than sediments mechanically dredged.

c. Mechanical Dredging. Mechanical dredges lose some of the interstitial water during the lift through the water column and in dewatering during transport. However, in comparison to hydraulic dredging, reduced disturbance and the absence of a slurry results in less opportunity for sediment-bound contaminants to go into solution. Dewatering of the material at the disposal site also produces less water than hydraulically dredged sediments. However, the efficiency of mechanical dredges at removal of the liquid phase of sediments is low in comparison to hydraulic dredging. During dredging and transport dewatering the loss of this phase could result in substantial loss of the more soluble contaminants, especially in less cohesive and coarser sediments that dewater rapidly. The use of watertight buckets and sealed transport containers (e.g., watertight barges) would significantly reduce this loss.

2.04.03 Sediment-Bound Contaminants. The vast majority of heavy metals and organic contaminants are associated with the fine-grained and organic components of the sediment. With certain exceptions such as ammonia, they tend to remain bound to particles during the dredging and disposal process. Therefore, the control of solids during dredging is highly correlated to the control of overall contamination. Greater turbidity and sediment resuspension levels for a given dredge result in lower removal efficiency, less confinement, and greater release of contaminants.

As a general rule, hydraulic dredges remove a greater percentage of the sediments at a dredging site than mechanical dredges. This is reflected in the lower sediment resuspension values for hydraulic dredges. However, to some extent, this is a function of the type of head being used. Active dredge heads (e.g., cutterhead) will often produce bottom turbidity equivalent to mechanical dredges. Passive heads (e.g.; plain suction, Pneuma) produce substantially less resuspension of sediments. The advent of shrouded, active dredge heads (mudcat, refresher, cleanup dredges) provides for removal efficiency, debris control, and lower resuspension throughout the water column. The hydraulic dredge breaks up the cohesion of *in situ* sediments. This makes the dredged sediment more difficult to consolidate and control at the disposal site than for mechanically dredged sediments. For hopper dredging, these suspended sediments and any associated contaminants will be lost at the extraction site if overflow is allowed.

Overall, the biggest differences between hydraulic and mechanical dredging sediment resuspension is seen in the middle and top portions of the water column (with the exception of hopper dredge overflow).

CHAPTER 3.0 DISPOSAL METHODS AND SITES

3.01 Introduction. Proper selection of dredging equipment and dredging technique is essential to economically remove and control contaminated sediments at the dredge site. However, disposal of these sediments is of equal or greater importance to project viability from environmental and economic standpoints. Implicit within the selection of a preferred disposal method or site are the efficiency of the dredging operation, the efficiency of the disposal method or site to retain the contaminants of concern, and the level of treatment and monitoring to be assumed to assure continued confinement or a controlled, acceptable release of those contaminants. Following a discussion of dredged material behavior when discharged from various dredges, this chapter discusses three generic disposal methods, open water, upland, and nearshore, in addition to off-site considerations as they apply to these three major methods. Secondly, a contaminant evaluation, similar to the one included in the previous chapter, examines the strengths and weaknesses of the generic disposal methods in successfully containing the various contaminant classes. Thirdly, specific disposal sites in the Commencement Bay area are identified based on criteria developed for this report. These sites are discussed and evaluated for their ability to meet anticipated needs for disposal of contaminated sediments from Commencement Bay. Although no sites outside of the Commencement Bay area are listed, options and limitations for off-site disposal are briefly addressed.

In our evaluation of disposal methods and sites, three major factors were considered:

- Cost - Includes site preparation, transportation, and other costs associated with initial or ongoing disposal of sediment, discussed in chapter 5.
- Limitations - Includes factors such as ownership, availability, capacity, location of material source, environmental effects on significant resources, and identification of data and information gaps.
- Containment - Includes the effectiveness in meeting the goal of maximum containment and minimum release of contaminants.

3.02 Transportation and Discharges from Various Types of Dredges. In order to assess the opportunities and problems associated with the disposal methods, some understanding of the behavior and characteristics of dredged material discharges from the various types of dredges is necessary. This will include transportation considerations as they bear on disposal operations. Chapter 2 dealt with sediment behavior as those sediments were removed from the dredge site. In this chapter, sediment behavior during the disposal operation is described.

a. Hopper Dredge. Hopper dredge characteristics are discussed in the previous chapter. During normal operations, once the hoppers have been filled, the drag arms are raised and the hopper dredge proceeds to the disposal site. During transport to the disposal site, the sediments tend to settle out and consolidate within the hopper. At the disposal site, the dredged materials are bottom dumped or pumped out and the dredge returns to the dredging site to reload.

Bottom dumping from hopper dredges normally involves open-water disposal. Most older hopper dredges dispose of the dredged material through hinged hopper doors in the bottom of the ship's hull which allows the materials to be spread over a site or dumped at once. Many of the newer hopper dredges are of the "split hull" design that dumps the entire load at once. Bottom-dump disposal produces a series of discrete discharges at intervals between one and several hours. When discharged, the dredged material falls through the water column as a well defined jet of high density fluid (figure 3-1). Ambient water is entrained during descent. Depending on the composition of the dredged material, most of it comes to rest on the bottom as a high density, fluid mass. Some material is carried away from the impact point by the horizontally spreading bottom surge created by the impact. This spread may extend a few hundred feet from the point of impact, settling as the turbulence of the surge dissipates. If a strong pynocline is present in the water column, some suspended finer material may concentrate and spread at this point. Testing with sediments from or equivalent to the site to be dredged would be necessary to determine whether a substantial loss of fines could be expected from hopper dredge discharge.

Some hopper dredges are equipped with pump out capability. Pump out discharge can be used for any disposal method. Dredges with this capacity have the flexibility to pump directly, bypassing the hopper, discharging like a conventional cutterhead pipeline dredge. Conventionally, the hopper dredge will fill its hopper, move to the discharge point and either pump the material overboard, inject it into the water column at depth, or pass the slurry through a pipeline to a nearshore or upland disposal site. Sediment behavior from this disposal operation will be very similar to that described for the cutterhead pipeline dredge.

b. Mechanical Dredge. Mechanical dredges remove the sediment at approximately *in situ* density. The sediment is placed in barges or scows for transport to an open-water disposal area or for rehandling directly into a confined, nearshore disposal area. The sediments can also be carried by trucks or other land conveyance. During transport there is usually very little return water to the aquatic environment, especially if the container is watertight. Some of the interstitial water will drain from the material. Although several barges may be used so that the dredging is essentially continuous, disposal normally occurs as a series of discrete discharges. In open-water disposal, the dredged material may be fluid mud similar to that in a hopper dredge, but often sediments that are mechanically dredged remain consolidated as large clumps and reach the bottom in this form with little release of interstitial water. The dredged material descends rapidly through the water column to the

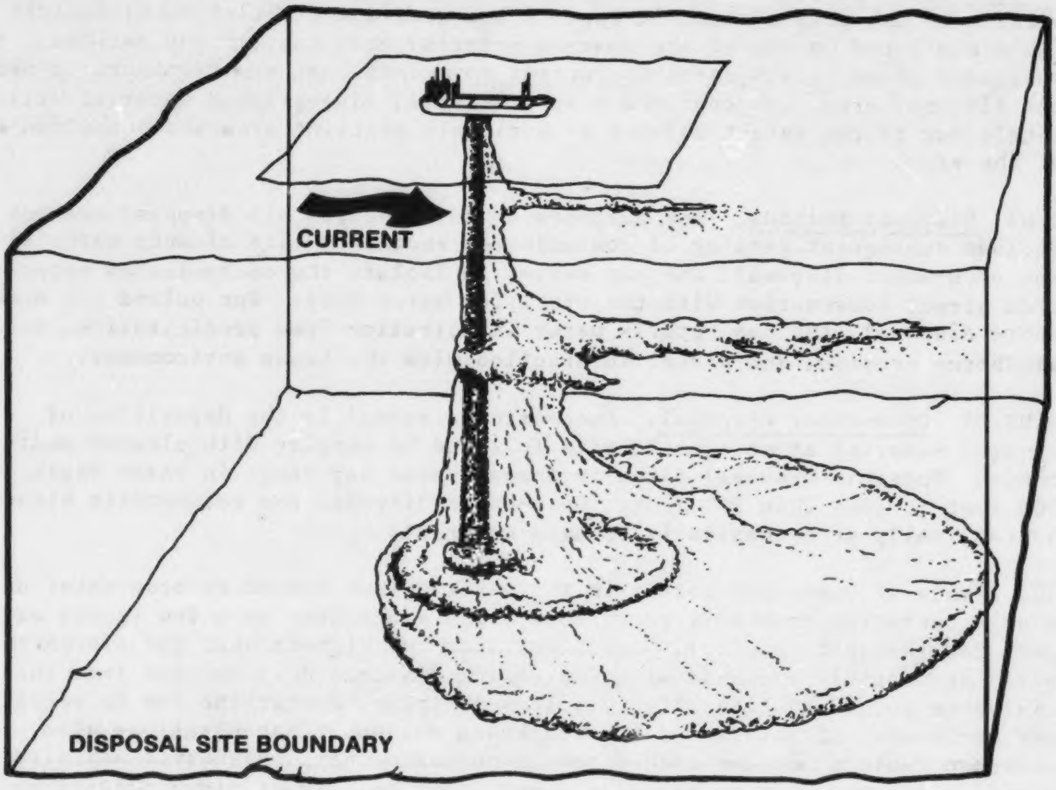


Figure 3-1. Bottom Dump Disposal of Dredged Material From a Hopper Dredge

bottom, and only a minor fraction of the material remains suspended. Optionally, sediments in the barge can be reslurried and discharged through a pipeline to any type of disposal site.

c. Cutterhead Pipeline Dredge. Hydraulic dredges, which include hopper dredges, produce a slurry of sediment and water. Transportation of the material through the discharge pipeline, however, differs dramatically from both hopper and mechanical dredges as the dredging and disposal operations are self contained and continuous. The material removed by the dredge is pumped in slurry through a continuous pipeline to the disposal area and discharge continues as long as the dredge is operating. Generally, a pipeline dredge can pump its slurry a limited distance from the dredge site; transporting the slurry further within the pipeline requires a booster pump. The original pumping distance varies according to the size of the dredge, the sediment type being pumped, and the topography over which it is being pumped. Upon discharge, coarse material, such as gravel, clay balls, or coarse sand, immediately settles in the disposal area and usually accumulates directly in front of the discharge point. At an open-water site, the fine-grained material settles to the bottom where it forms a low gradient circular or elliptical fluid mud mound on top of the coarser material that has already settled. The suspended plume is subjected to current movements that can transport it out of the disposal area. In confined disposal areas, fine-grained material will settle out to the extent allowed by available settling area and retention time of the site.

3.03 Disposal Methods. For purposes of this report, all disposal methods include subsequent capping of contaminated sediments with cleaner material. For open-water disposal, the cap serves to isolate the contaminated material from direct interaction with the overlying water body. For upland and nearshore disposal, the cap retards water infiltration from precipitation, prevents windborne erosion, and direct interaction with the human environment.

3.03.01 Open-Water Disposal. Open-water disposal is the deposition of dredged material at an aquatic site followed by capping with cleaner sediments. Possible disposal sites in Commencement Bay range in water depth from 500 feet to less than 100 feet. Open-water disposal can accommodate either hydraulically or mechanically dredged material.

The levels of suspended solids in the water column around an open-water discharge operation generally range from a few hundredths to a few tenths of a part per thousand (p.p.t.). Concentrations are highest near the discharge point and rapidly decrease with increasing distance down current from the discharge point and laterally away from the plume centerline due to settling and horizontal dispersion of the suspended solids. Concentrations also decrease rapidly between each discrete hopper or barge discharge and after a pipeline is shut down or moved to a new location. Under tidal conditions, the plume will be subject to the tidal dynamics of the particular bay, estuary, or river mouth where the discharge activity takes place.

One concern with open-water disposal is accurate placement of the contaminated sediments and capping material. Bottom-dump barges (filled by a mechanical dredge), followed by bottom-dump hopper dredges, can allow considerable point accuracy and consolidation of material over conventional cutterhead pipeline dredge and hopper dredge pump out discharges. There are, however, depth and current limitations. These vary according to site conditions.

A submerged diffuser system (figure 3-2), originally designed by the U.S. Army Corps of Engineers, is being field tested in the Netherlands. The diffuser is designed to minimize water column turbidity by pipeline and hopper pump out and allow equal or more accurate placement than the bottom-dump method and in greater water depths. This system eliminates all interaction between the slurry and upper water column by radially discharging the slurry parallel to and just above the bottom at a low velocity. As presently designed, the diffuser/barge system can be used in water depths up to 40 feet and can be readily modified to discharge to 100 feet. Technology that could extend its use to much greater depths is currently available.

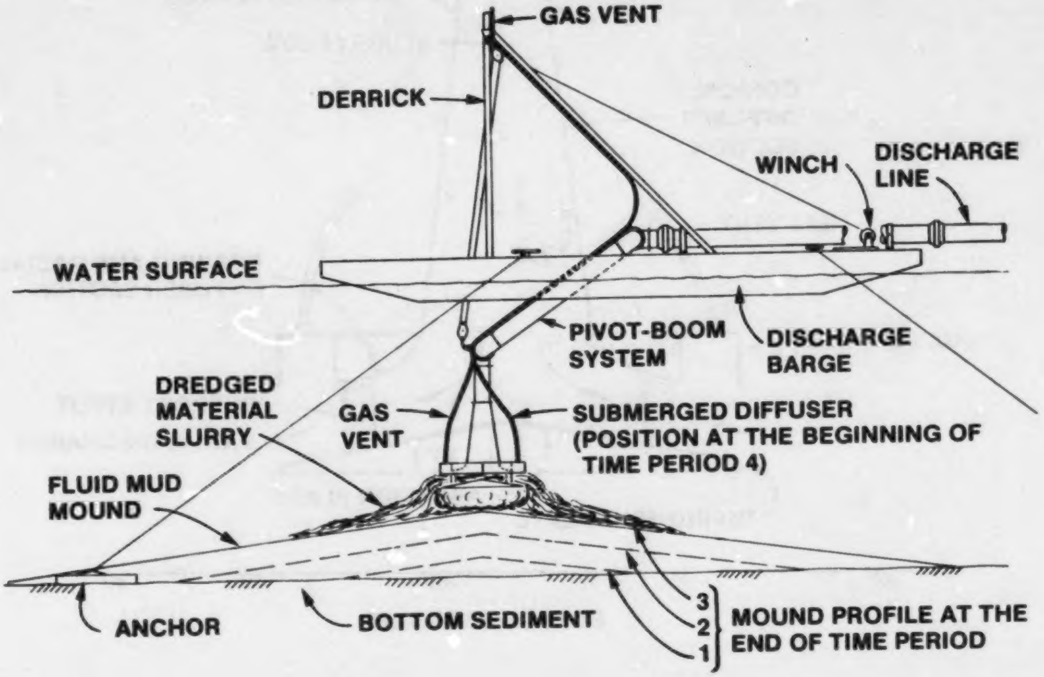


Figure 3-2. Submerged Diffuser System

The diffuser (figure 3-3) reduces the velocity and turbulence associated with the discharged slurry by routing the flow through a vertically oriented, 15-degree diffuser with a cross sectional area ratio of 4:1, followed by a combined turning and radial diffuser section that increases the overall area ratio to 16:1. The flow velocity of the slurry prior to discharge is reduced by a factor of 16, yet the dredge's discharge rate (slurry flow velocity x pipeline cross sectional area) is unaffected. The radial discharge area of the diffuser can be adjusted and thus both thickness and velocity of the discharged slurry can be controlled.

A discharge barge is used in conjunction with the diffuser to provide both support and capability for lowering the diffuser to within 1 meter (m) of the bottom at the beginning of the disposal operation and raising it as the fluid mud accumulates. The barge also provides a platform for the diffuser while it is being adjusted, serviced, or moved to a new site and can provide moorage and pump out capabilities for clamshell barges and hopper dredges.

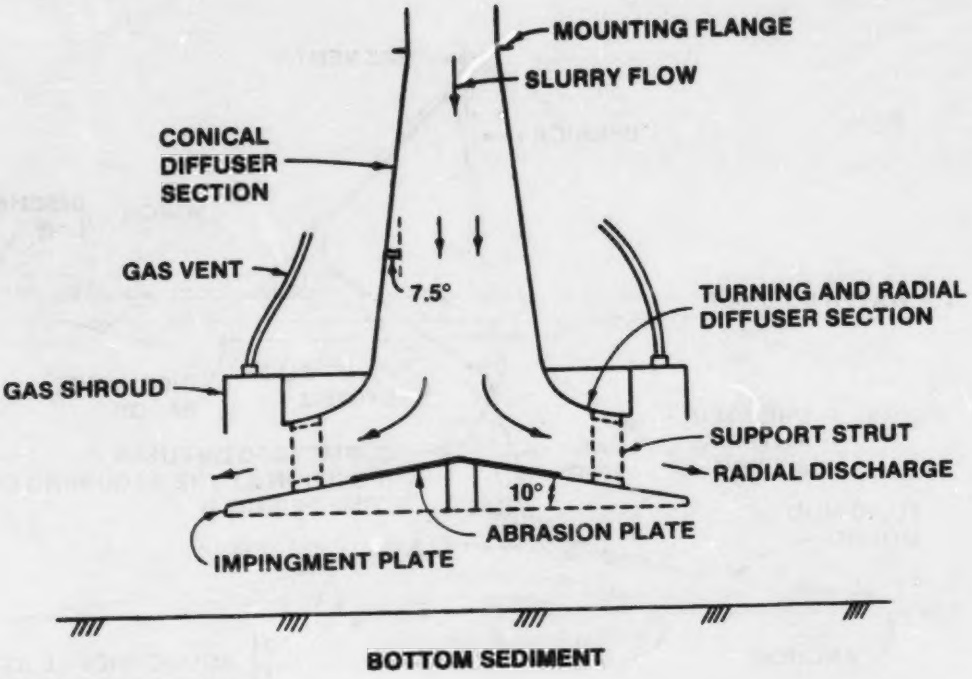


Figure 3-3. Submerged Diffuser

Further discussion of capping and use of the submerged diffuser is contained in chapter 4. The cost of using the submerged diffuser is discussed in chapter 5.

a. General Site Criteria. An open-water disposal site for contaminated sediments that are capped would be best located in a stable, low-energy area. Generally, these areas lie below the active intertidal zone and preferably below the depth of storm wave influence. Ideally, the area should be undergoing net accretion. All of these factors contribute to long-term stability of the cap and reduce convective forces that can increase loss of contaminants through the cap. While the depth of the site is theoretically unlimited (by use of vertical pipeline diffuser discussed earlier), experience with the diffuser is minimal at this time. Other considerations that may require detailed study include an assessment of resources at the site, geotechnical data, and bottom currents.

Because the ideal open-water disposal site may not be available, its shortcomings may be somewhat relieved by use of the appropriate capping material. The material should be able to resist erosion forces at the site. Grain size should be similar to or coarser than the surrounding bottom sediment, at least sand or denser material. The cap can be gradually built up by hopper dredge discharge as the dredge moves, thus "feathering" coarser materials onto finer, contaminated sediments or directly placed by vertical pipeline diffuser. Surface release is preferable for uncontained, mounded sediments; the vertical pipe allows underwater diking (if needed) and rapid cap placement over sediments contained in a depression. Thickness of the cap will depend on specific site conditions, including depth of potential bioturbation, mobility of contaminants, and current velocities, but a minimum of 3 feet is recommended.

b. General Designs. This report describes four general designs for open-water sites (figures 3-4 to 3-7): deepwater mound, deepwater confined, shallow water confined, and waterway confined. All of the designs have in common the capping of the contaminated sediments placed at the site, with the surface of the cap remaining aquatic. This is differentiated from nearshore disposal where the final site elevation extends above high water.

One design not described here is a shallow water mound: this design was eliminated from detailed consideration due to the relatively high energies characteristic of shallow water environments. Although there may be specific sites in shallow water environments that are quiescent enough to make mounding viable, the construction considerations are virtually those of deepwater mound with a thicker cap.

(1) Deep-water Mound. Deep-water mounding is the most simple design evaluated (figure 3-4). Deep water is any depth below the influence of storm waves, which will vary between sites. Theoretically, depths are unlimited, although in fact the ability to accurately place contaminated and capping materials establishes practical limits. Most deep-water sites would be between 60 and 500 feet deep. Dredged material is transported to the identified disposal site and placed on the bottom by bottom dump or vertical pipeline diffuser. No attempt is made to "line" the bottom; that is, separate the contaminated sediment placed from the existing substrate or to confine the spread. However, the contaminated sediments should be concentrated as much as possible in one location and partial containment may be possible by use of natural depressions. Once the contaminated material is placed, it is capped with clean, coarse material placed by any of the methods previously described. Since the deep-water site was presumably selected for its low energy environment, a relatively thin cap (3 feet) should be sufficient depending on the type of material used. As the contaminated material is mounded without confinement on the bottom, the major construction problem is to insure that sufficient capping material is properly placed to completely cover the mounds to sufficient depth (properly designed for the hydrodynamic regime and bioturbation potential). So long as the cap remains in place, the major pathways of concern for contaminant loss are soluble diffusion and convection over time. Due to water depth, movement of ground water is expected to be substantially absent and contaminant movement through the ground consequently reduced.

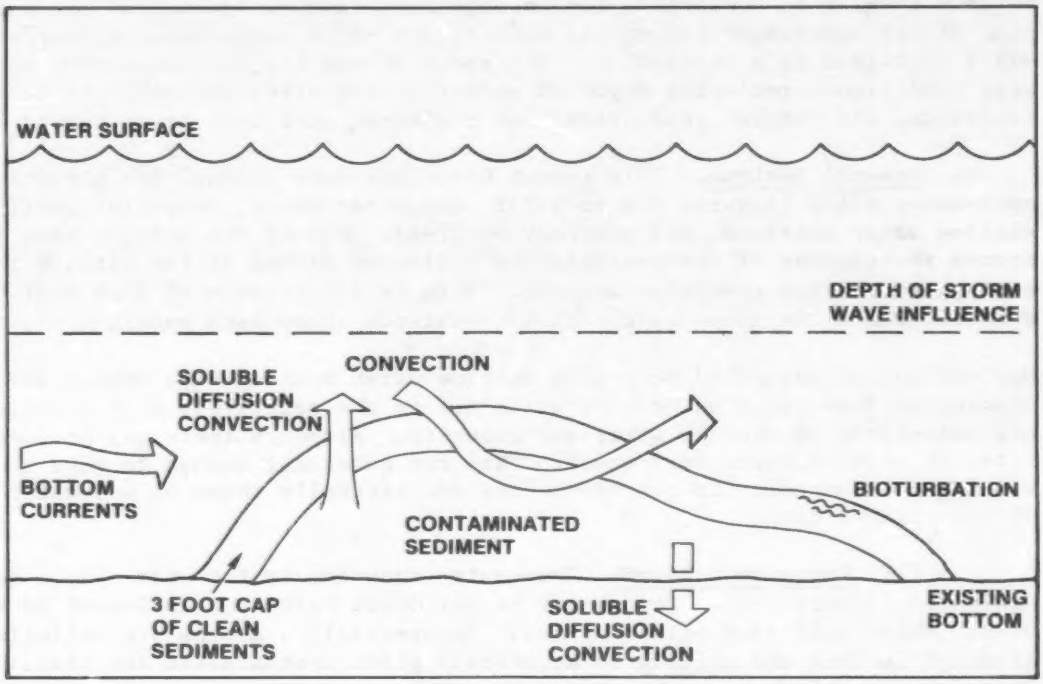

WATER SURFACE
DEPTH OF STORM WAVE INFLUENCE
CONVECTION
SOLUBLE DIFFUSION CONVECTION
BOTTOM CURRENTS
BIOTURBATION
CONTAMINATED SEDIMENT
3 FOOT CAP OF CLEAN SEDIMENTS
SOLUBLE DIFFUSION CONVECTION
EXISTING BOTTOM

Figure 3-4: Deep-Water Mound

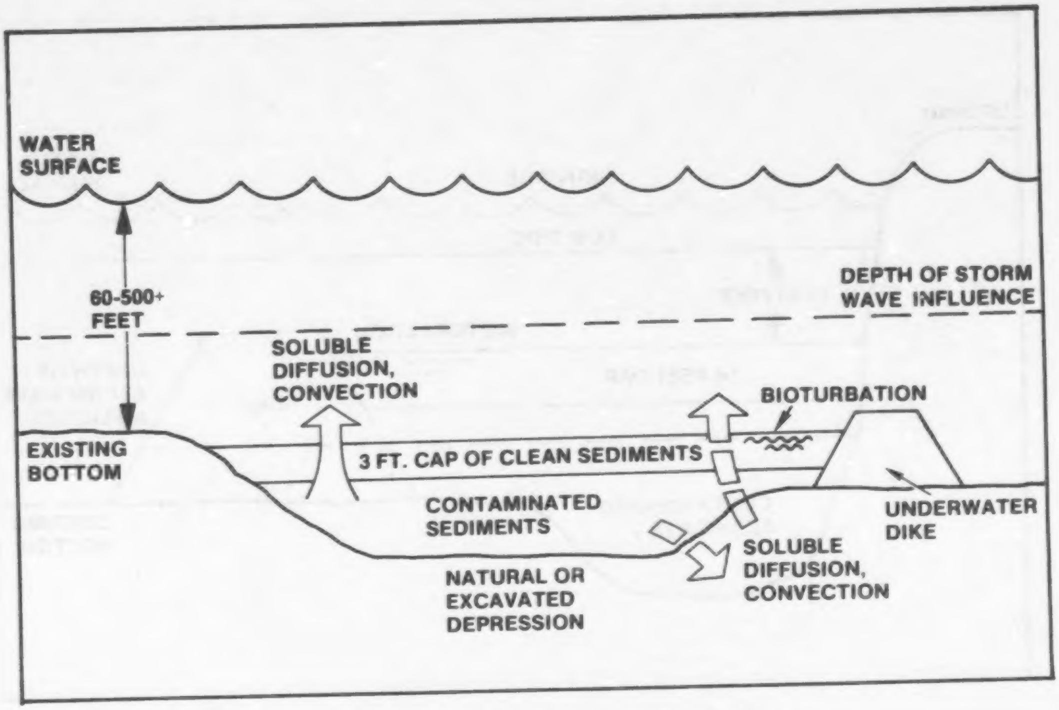

WATER SURFACE
60-500+ FEET
DEPTH OF STORM WAVE INFLUENCE
SOLUBLE DIFFUSION, CONVECTION
BIOTURBATION
EXISTING BOTTOM
3 FT. CAP OF CLEAN SEDIMENTS
CONTAMINATED SEDIMENTS
UNDERWATER DIKE
SOLUBLE DIFFUSION, CONVECTION
NATURAL OR EXCAVATED DEPRESSION

Figure 3-5: Deep-Water Confined

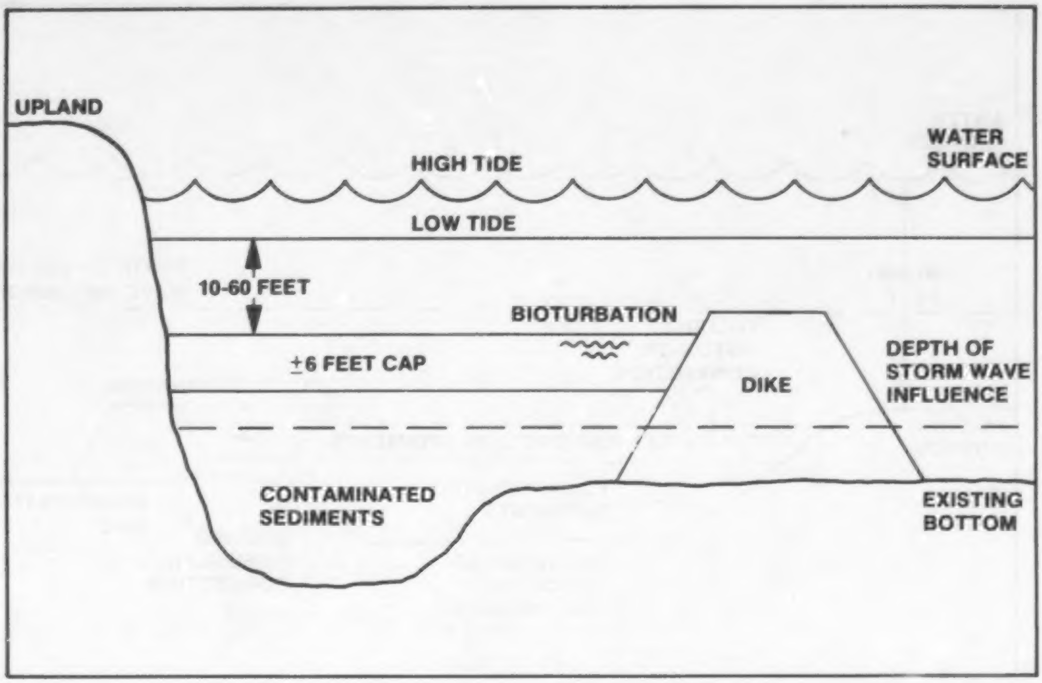


Figure 3-6: Shallow-Water Confined

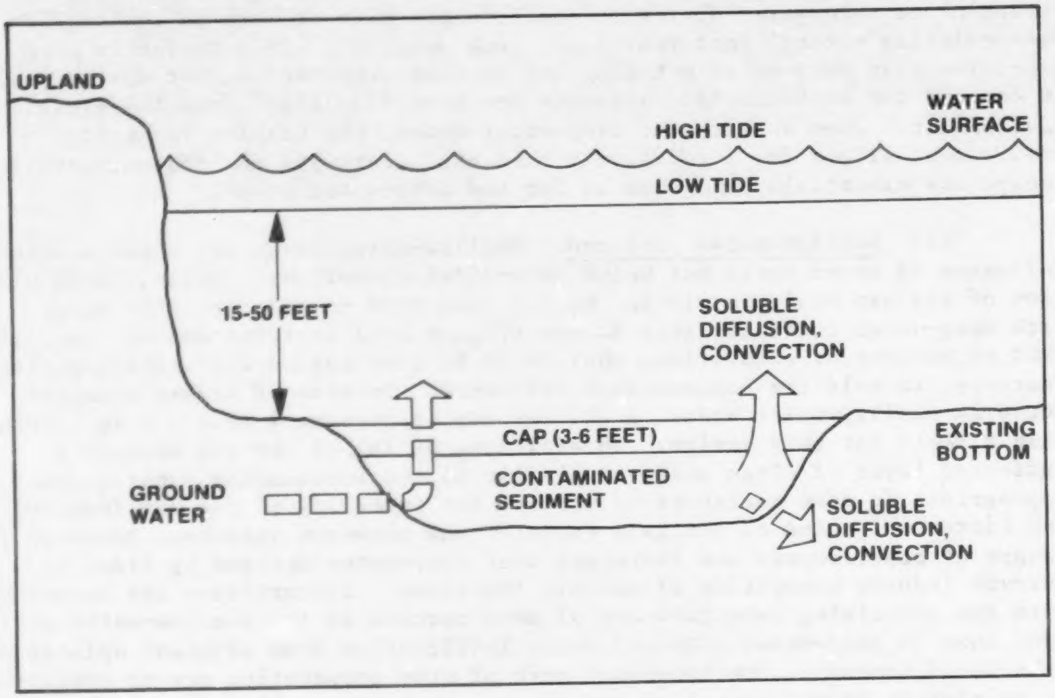


Figure 3-7: Waterway Confined

(2) Deep-water Confined. This design differs from deep-water mounding in that materials are placed in a natural or manmade depression in the sea floor to aid confinement (figure 3-5). Use of a vertical pipe allows construction of underwater diking to encircle the site or work in combination with existing natural features (e.g., rock outcrop). This design is more expensive than deep-water mounding due to site preparation, but may be easier to cap and the contaminated sediments are more "isolated" from the aquatic environment. Just as with the deep-water mound, the stable, low energy environment allows for a relatively thin cap. Pathways for contaminants to escape are essentially the same as for the deep-water mound.

(3) Shallow-water Confined. Shallow-water areas are those within the influence of storm waves but below intertidal elevations. Hence, final elevation of the cap would be within the -10 feet MLLW to -60 feet MLLW range. As with deep-water confined, this design (figure 3-6) includes manmade containment structures or excavation, wholely or in combination with existing natural features, to hold the contaminated sediments. Because of higher energies found in shallow-water areas, a thicker cap is necessary (e.g., 6 feet rather than 3 feet) for this design. In addition, burial of the cap beneath a buffering layer of clean sediment similar to the surrounding substrate may be appropriate in some instances to protect the integrity of the cap from erosion and bioturbation and to mitigate esthetic and resource impacts. Pathways for escape of contaminants are increased over deep-water designs by tidal or current induced convection of soluble fractions. Bioturbation and leaching into the underlying substrata are of more concern in the shallow-water environment than in deep-water. Ground water infiltration from adjacent uplands may also be of concern. The increased cost of site preparation may be partially or completely offset by savings in transportation cost to a deep-water site.

(4) Waterway Confined. Although this design (figure 3-7) is very similar to the option of burial of sediments in shallow-water areas, it differs in one very important respect. The shallow-water confined design can apply to many different geographic locations: open water, aquatic shelves near an urban shoreline, or relatively pristine environments. In these environments, agitation by currents, tides, and storms are factors that must be countered by the site design (i.e., a thicker cap, a buffer over the cap, frequent cap maintenance). In the waterway design, a confined pit is excavated deep within and into the bottom of an existing waterway. Preferably, the disposal site should be located in an area that will not be dredged. Otherwise, the disposal pit must be of sufficient depth to be well below anticipated dredging depths. This pit may be lined (Rotterdam-Putten Plan, see appendix 2a) or not, but the contaminated sediments from elsewhere in that waterway or harbor are placed in the excavated pit, the pit capped, and some of the excavated material replaced over this cell of contaminated material to about the original bottom contour. Hydraulic energies associated with the Commencement Bay waterways are much less than other shallow water environments. In addition, because existing sediments in Commencement Bay waterways show relatively high levels of contaminants, other contaminated material placed in the confined pit would be generally similar to the surrounding material. This would substantially reduce the concern associated with leaching of contaminants to underlying substrates. Escape pathways are virtually identical to shallow-water confined, though reduced in intensity to levels similar to the deep-water designs.

3.03.02 Upland Disposal. Upland disposal involves the placement of dredged material in environments not inundated by tidal waters (figure 3-8). Upland disposal sites are normally diked, confined areas that retain the dredged solids while allowing the carrier water to be released, and as such are most often associated with hydraulic dredges (pipeline or hopper with pump out capability). Upland sites can also accept dredged material that has been dewatered elsewhere and transported in by truck or rail (if hydraulically dredged) or has simply been loaded directly into trucks or railcars by mechanical dredges. Upland disposal sites may be located immediately adjacent to, or removed great distances from, the dredging site.

As nearly all upland disposal sites are diked areas, the major components of a containment area are shown schematically in figure 3-9. The two objectives inherent in design and operation of containment areas are to provide adequate storage capacity to meet the dredging requirements and to attain the highest possible efficiency in retaining solids during the dredging operation. Basic guidelines for design, operations, and management of containment areas are presented by Palermo, et al. (1978) and Montgomery, et al. (1983).

Behavior of hydraulically dredged material discharged into a containment site has been generally described in section 3.02. The effluent is discharged from the containment site over a weir. This effluent is normally characterized by its suspended solids concentration and rate of outflow. Flow over the weir is controlled by the static head and the effective weir length provided. To promote sedimentation, the inflow slurry is encouraged to pond; a minimum ponding depth of 2 feet is recommended for a continuous disposal activity. Ponding depths less than 2 feet may be acceptable if the dredging occurs intermittently. The depth of pond water is controlled by elevation of the weir crest. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area that is smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones further reduce the effective surface area, where sedimentation occurs, to considerably less than the ponded surface area. Spur dikes (internal dikes) can be used to improve settling efficiency by modifying flow patterns through the site, modifying currents, and allowing more time for settlement (figure 3-10).

Several expedient measures can be employed to enhance retention of the suspended solids within a containment area of a given size before effluent discharge to receiving waters. They include: intermittent pumping, increasing the depth of ponded water, increasing the effective length of the weir, temporarily discontinuing operations, or decreasing the size of the dredge.

a. General Site Criteria. Normally, upland site criteria are related to the method of dredging employed and the volume of material dredged. Specific site criteria for selection and evaluation of potential upland disposal sites in the Commencement Bay area were developed for this report. These criteria and their application are explained in section 3.05 and generally relate to site size (which affects its capacity), distance from the harbor area where most contaminated sediments are expected to originate, site elevation, and

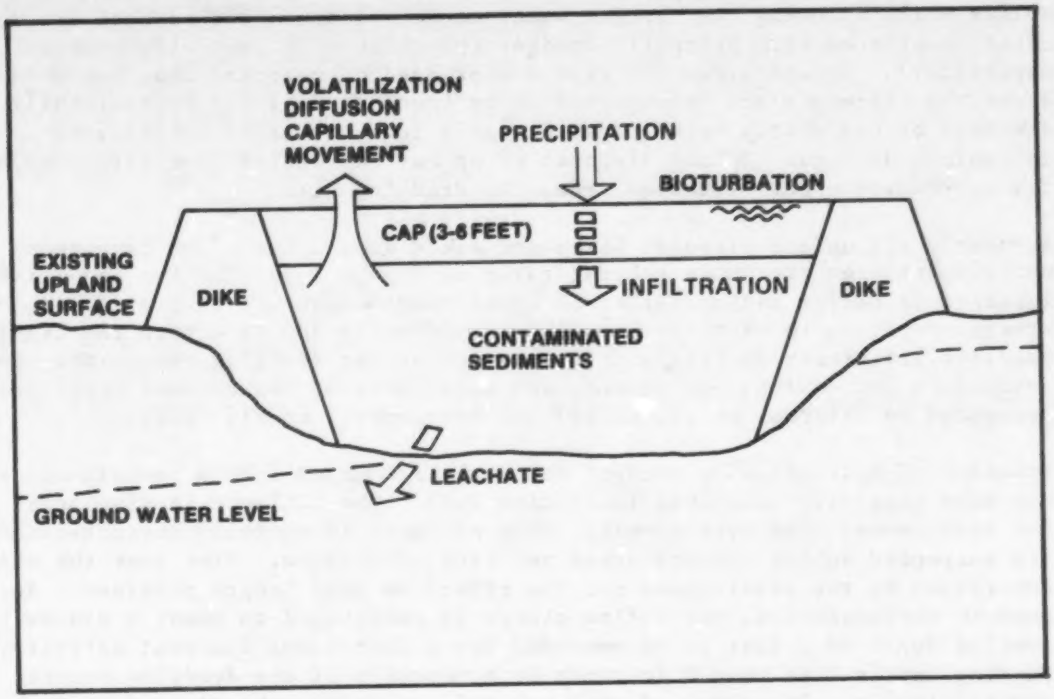
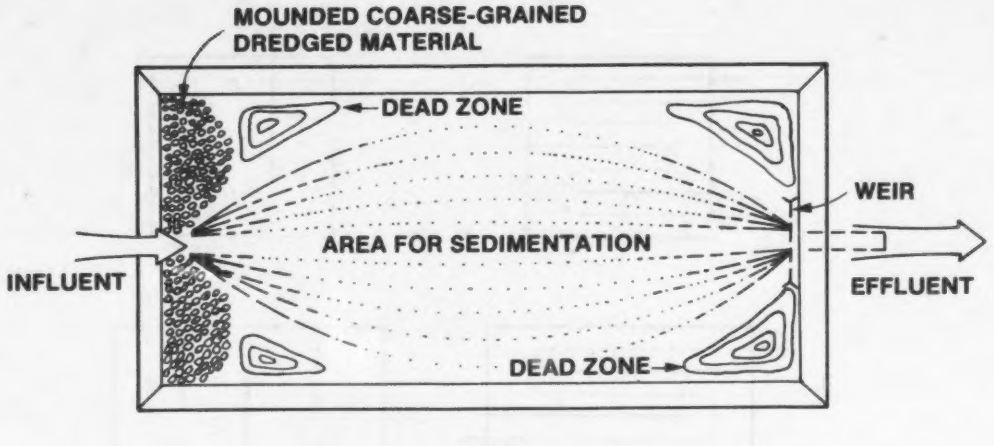
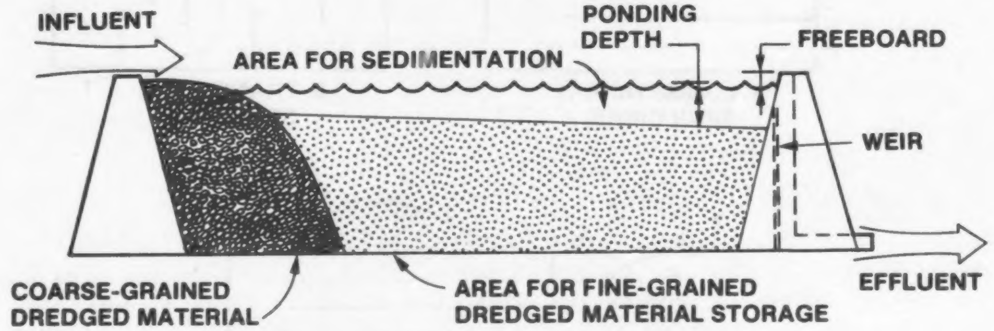


Figure 3-8: Upland Disposal

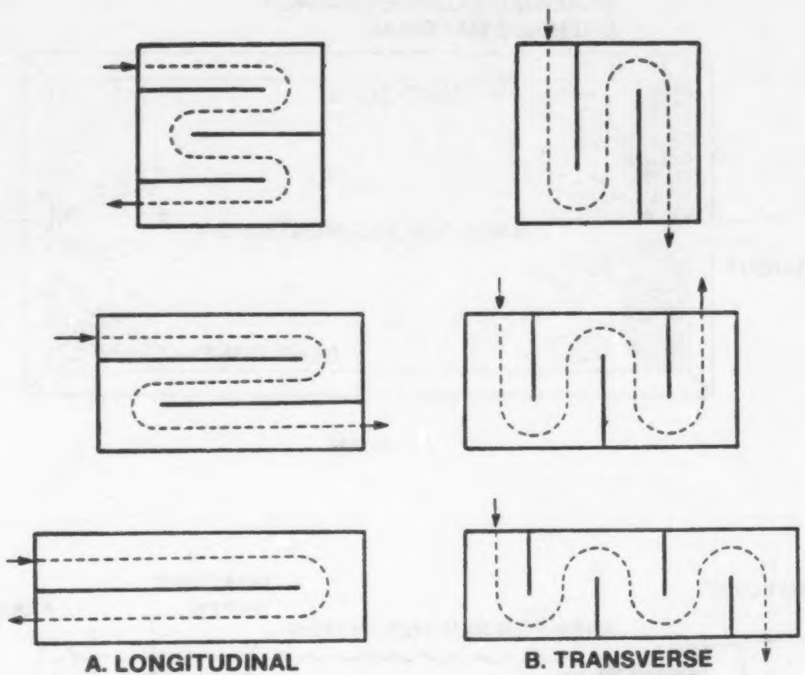


PLAN


INFLUENT
PONDING DEPTH
FREEBOARD
AREA FOR SEDIMENTATION
WEIR
EFFLUENT
COARSE-GRAINED DREDGED MATERIAL
AREA FOR FINE-GRAINED DREDGED MATERIAL STORAGE

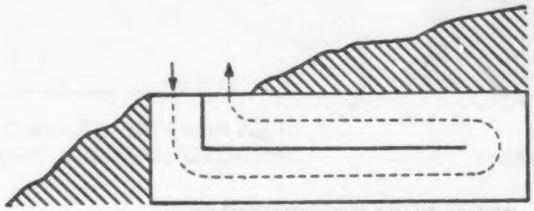
CROSS SECTION

Figure 3-9: Conceptual Diagram of a Confined Dredged Material Disposal Site



A. LONGITUDINAL SPUR DIKES

B. TRANSVERSE SPUR DIKES



C. COMBINATION SPUR DIKES FOR DIFFICULT ACCESS AND SHAPE RESTRICTIONS

Figure 3-10: Examples of Longitudinal and Transverse Spur Dike Configurations

amount and cost of site preparation. Beyond these generic considerations, final site selection criteria will depend on answers to a number of environmental and engineering concerns. Hydrologic conditions, including the presence, depth, extent, and use of ground water, will be critical in all cases. Of equal concern and related to ground water is site foundation (geology, soils, etc.) and the presence of hazardous materials onsite that will require identification and removal prior to site use. Many of the other information needs described for selection of open-water disposal sites apply to upland sites as well.

b. General Designs. The design of most upland disposal sites is similar. In most cases, earthen dikes are constructed to enclose the site. In some instances, however, the site may be partially or entirely excavated; although excavation is typically much more expensive than dike construction, especially where large acreages are involved as is the case in Commencement Bay. Because of this, excavation was not considered in this report. The only consideration not common to diking and excavation is dike failure; however, proper design eliminates this as an important problem.

3.03.03 Nearshore Disposal. Nearshore disposal is distinguished from both open-water and upland disposal methods by placement of the dredged material in an aquatic environment (normally marine and tidal) but the final elevation after filling is above water (figure 3-11). Nearshore disposal sites for contaminated sediments are always diked, confined areas. These sites normally are used in association with hydraulic dredges but can accommodate dredged material from mechanical dredges directly, bottom-dump barges, and direct dumping from trucks and/or railcars.

General site criteria and information needs are identical to upland disposal and include, in addition, the water exchange and movement concerns of shallow water confined designs. Designs most frequently involve diking of old harbor waterways that are no longer actively used. Nearshore excavation is possible, although normally too expensive for consideration. One site exists in Commencement Bay that originally was excavated and used as a graving dock. Such opportunities are rare.

3.04 Contaminant Efficiency of Disposal Methods.

The evaluation of contaminant behavior during dredging that is contained in chapter 2 carries over to disposal, especially for pipeline dredging. For purposes of this report, disposal of mechanically dredged sediments begins at the time sediments are placed in the barge, truck, or railcar and includes their transportation to, as well as the actual discharge at, the disposal site. With hydraulic dredges, dredging and discharge are all part of a single, extended process. The contaminant evaluation for this disposal chapter will cover the time following discharge of the slurried sediments into a contained upland or nearshore site or into an aquatic site.

3.04.01 General. The properties of a dredged sediment, and the short- and long-term physical and chemical environment of the dredged material at the

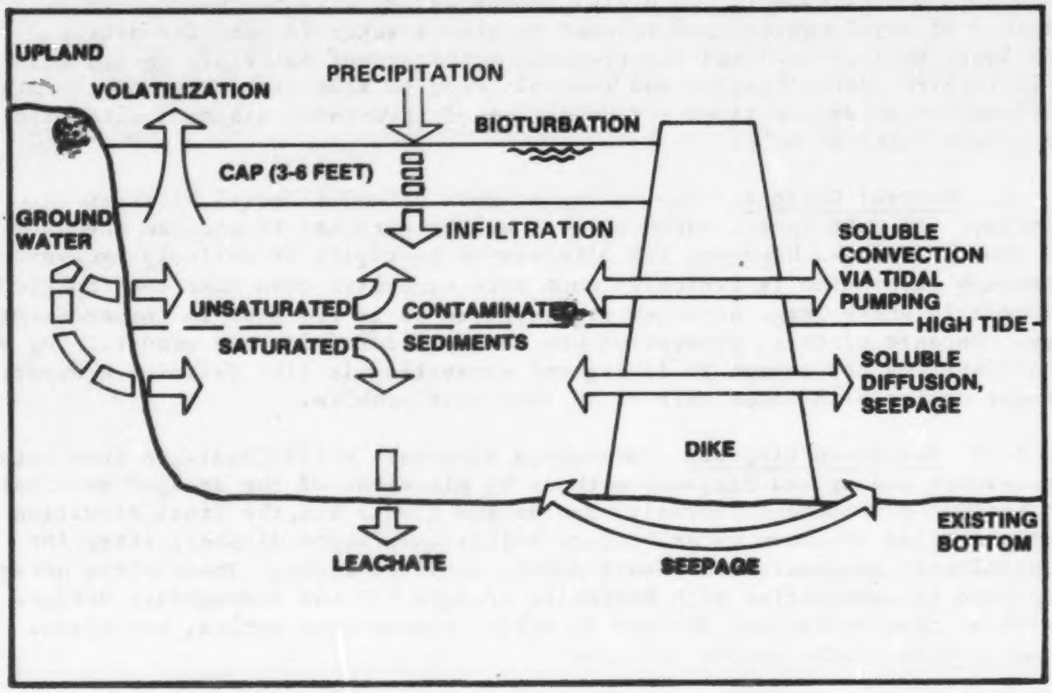


Figure 3-11. Nearshore Disposal

disposal site, influences the fate and environmental consequences of contaminants. The processes involved with release or immobilization of most sediment-associated contaminants are regulated to a large extent by the physical-chemical environment at the disposal site. The major parameters that influence contaminant behavior in dredged material are the amount and type of clay; organic matter content; amount and type of cations and anions associated with the sediment; the amount of potentially reactive iron and manganese; and the oxidation-reduction, pH, and salinity conditions of the sediment. Although each of these sediment properties is important, much concerning the release of contaminants from sediments can be inferred from the clay and organic matter content, initial and final pH, and oxidation-reduction conditions. Much dredged material is high in organic matter and clay and is both biologically and chemically active. It is usually devoid of oxygen and may contain appreciable sulfide. These sediment conditions favor effective retention of many contaminants, provided the dredged materials are not subject to mixing, resuspension, or changes to their chemical environment. Sandy sediments low in organic matter content are much less effective in retaining metal and organic contaminants. However, sandy sediments tend not to accumulate contaminants unless a contamination source is nearby. Should contamination of these sediments occur, potentially toxic substances may be readily released upon mixing in a water column or by leaching (USACE, 1983b).

Many contaminated sediments are in a reduced state and at near neutral pH (7.0), initially. Disposal into quiescent waters maintains anaerobic conditions and favors contaminant retention. Certain sediments that are noncalcareous and contain appreciable reactive iron and, particularly, reduced sulfur compounds, can become moderately to strongly acid as result of drying and subsequent oxidation. These conditions occur in upland disposal sites and in the upper, unsaturated layers of nearshore disposal sites. This altered environment greatly increases the potential for the release of heavy toxic metals. In addition to the effects of pH changes, the release of most heavy metals is influenced by oxidation-reduction conditions. Thus, sediments which tend to become strongly acid upon drainage and long-term oxidation may pose a high environmental risk (USACE, 1983b).

Mobility implies a quantifiable rate process and is a function of the chemical species, the solvent (water), the type of soil/sediment matrix, the physical state of the system, chemical concentration levels, and certain geometric factors. These factors are discussed by Thibodeaux (1984) (appendix 2a).

There are several physical, chemical, and biological processes that can result in transport of contaminants through a sediment/water environment. These mechanisms include the following:

- o Diffusion of dissolved chemical species down a chemical concentration gradient and through the sediment-water interface.
- o Convection and dispersion of dissolved chemical species (and fines) due to water flow through the sediment (ground water, precipitation, runoff, tidal action) and sediment consolidation.
- o Bioturbation of the sediment.
- o Scour and suspension of surface sediment particles by bottom water currents.
- o Gas generation and ebullition within and through the sediment/water interface.

3.04.02. Volatile Phase Contaminants. To a limited extent, the loss of volatile contaminants during disposal will depend on the dredging technique and controls employed. Conditions and concerns of mechanical versus hydraulic dredging are contained in chapter 2; these are most important for volatile contaminant release in the short term, during or immediately following discharge. Once the contaminated sediments have been placed in the disposal sites and capped, the number and strength of contaminant transport mechanisms operating on the material become more important factors. For example, mechanically dredged material contains less in situ water than does pipeline slurry. The water contained in the dredged slurry acts as its own transportation medium to spread the sediment through the disposal site and at the same time provides a buffer reducing the sediment's exposure to air. For volatile contaminants, this aids retention. Mechanically, and occasionally hydraulically, dredged material may require reworking with a bulldozer in upland and some nearshore disposal sites, an operation that increases the opportunity for loss of volatile contaminants.

a. Open-Water Disposal. Transport by hydraulic pipeline is covered as a part of dredging. A general description of transportation concerns for mechanical dredging is included in section 3.02. Because of the exposure time to air that occurs with mechanically dredged sediments in barges, some loss of volatile contaminants will occur during transportation of the material to the disposal site. Once placed in an open-water site and capped, escape will be limited to minor gas diffusion through the cap and bioturbation. The rate of loss can be controlled by maintenance of the cap's integrity. Due to the anaerobic conditions of the subaquatic environment, volatile mobility will likely be an order of magnitude below upland or nearshore disposal.

b. Upland Disposal. If the material has been mechanically dredged, some loss of volatile contaminants will have occurred during transport to the site. No dewatering of the material will be necessary. Hydraulic placement of sediments results in loss of volatiles in proportion to their exposure to air. Submerging the pipeline outlet and not allowing a splash or "glory hole" to develop aids retention of volatiles. A fraction of the volatiles will be lost into the atmosphere as the slurry moves through the site. After the dredged sediments have settled out and the site is capped, volatile contaminant mobility continues via diffusion, air convection over and through the caps, and possibly barometric pressure pumping. Capping material and thickness will control the rate of release. As the sediment dewaters, volatiles that are soluble or sediment bound in the presense of water may be released.

c. Nearshore Disposal. Loss of volatile contaminants from use of a nearshore disposal site is substantially the same as upland disposal, with the exception that not all of the contaminated sediments will become unsaturated. Submerging the pipeline outlet in the disposal site would be easier to do at a nearshore site than an upland site. Overall, rate of loss would approximate that of upland disposal.

3.04.03 Soluble Phase Contaminants. Nearly all chemical contaminants are soluble to some degree and can be found in association with all three phases of the sediment (gas, liquid, and solids). In terms of their affinity for going into solution, they can be characterized as highly soluble (will easily exchange from one phase to another) or slightly soluble (will not easily exchange or require special conditions). This degree of solubility depends on a variety of factors and can change as specific conditions are altered by the act of dredging, during transport of the dredged material, during its discharge into the disposal site, and following its disposal and capping. The first three actions occur during a very short time frame and their influence on contaminant mobility is relatively instantaneous with regard to evaluating disposal methods. The long-term condition changes and effects on contaminant phase, particularly with regard to solubility, are of greater concern and complexity.

A percentage of the potentially soluble contaminant fraction will be in solution in the interstitial water of the sediment. The remainder will still be bound to sediment particles. In this way, an equilibrium exists on a small scale, with the fraction of chemical contaminant potentially available for short-term release during dredging or disposal operations approximating the interstitial water concentrations and the loosely bound fraction in the sediments (chapter 2.0). Hydraulic dredging, by more thoroughly agitating the sediments, releases more of the interstitial water from the sediments and allows new water to contact the sediment bound fractions. This increases the propensity for any loosely bound fractions to exchange, but provides greater dilution of the contaminant laden water than does mechanical dredging. The greater efficiency of hydraulic suction removes contaminated interstitial water from the dredging site along with the slurried sediments, and the issue is transferred to disposal. Mechanical dredges release less of the interstitial water overall than do hydraulic dredges. If a watertight bucket is used, only at the edges of the dredge cut is interstitial water immediately lost. Thus, a smaller volume of sediment is exposed to new water and exchange potential. Most of the sediment and interstitial water dredged by a watertight bucket remain consolidated as they are placed into the barge, truck, or railcar for transport to the disposal site. Some of the interstitial water will drain from the sediments during transport and will be lost to the surrounding environment (if the container is not watertight) or will be lost or may require treatment at the disposal site (if the container is watertight). These are short-term releases.

Once deposited at the disposal site and capped, the concern for retaining soluble contaminants becomes complex. Contaminant fractions that were tightly bound to the sediment particles can, over time and due to altering conditions, become more prone to go into solution. This is especially true for heavy metals when placed in upland disposal sites. Under saturated conditions, many metals remain tightly bound to the sediments. In unsaturated conditions, where oxidation can occur, these contaminants can become highly soluble and readily leach to surface runoff or ground water percolating through the material. Changes in pH have similar implications for other compounds. Therefore, long-term releases of soluble fractions have greater and less understood potential for adverse effects.

a. Open-Water Disposal. Whether hydraulically or mechanically dredged, those soluble fractions released in the short term will be lost in the receiving waters. This will occur immediately upon discharge and continue until the disposal site is capped, although at a much slower rate once the material has come to rest. Immediately following capping and for an indeterminate transient period, no contaminants will be released, being encased by the cap and the sides and bottom of the disposal site. Over time, aided by diffusion and convection through the cap, soluble contaminants will begin to migrate into the clean cap material. Ultimately, these contaminants will saturate the cap material, decreasing in concentration level as they move through the cap, and be released into the overlying water column. Because physical, chemical, and biological conditions are relatively stable at deep-water sites, soluble contaminant loss would be gradual and the volume of overlying water offers substantial dilution. A management technique to further delay this long-term release is to add more capping material. Some migration of contaminants into interstitial water of underlying sediments through diffusion is also possible. Bioturbation is another source of contaminant release. Maintenance of the integrity of the cap is the maximum control.

b. Upland Disposal. Placement of contaminated sediments in an upland disposal site by hydraulic dredge would produce a large quantity of water containing soluble contaminants extracted and diluted from the sediments. Depending upon the types of chemicals released, treatment of this water prior to discharge back to the aquatic environment may be necessary. Mechanically dredged material will have less water to treat, if treatment is necessary, though contaminant concentrations are likely to be higher in this water. By use of upland disposal, soluble contaminants from this short-term release can be controlled and treated rather than lost. However, over time this environment is less stable than is the open-water environment. As the sediments drain, physical and chemical conditions change and affect the stability of some contaminants, causing them to go into solution. The cap can be designed to retard volatilization and precipitation entry, but seepage into and out of the site will allow contaminants to escape. Lining would retard soluble contaminant escape, but not totally eliminate it in the long term. Leaching into ground water is a major concern. However, just as upland disposal sites offer the greatest control possibilities for the effluent, they offer the greatest opportunity for controlling and treating (as necesary) the release of soluble contaminants over the long term. Further discussion is provided in chapter 4.

c. Nearshore Disposal. In comparison to upland disposal, nearshore disposal possesses many of the same concerns for soluble contaminants, although fewer opportunities for control exist (see chapter 4). In the short term, control and treatment of the contaminant laden effluent from either hydraulic or mechanical dredging is possible. Once filled and capped, the upper layers of contaminated sediment will drain until two distinct levels form. The lower level of sediment will continue to be saturated as a result of precipitation and ground water infiltration as well as marine water intrusion. Soluble contaminants will release through diffusion and convection as a result of tidal pumping and seepage. The upper sediment layer will drain over time and carry soluble contaminants into the lower, saturated sediments. As the upper layer of material becomes more "upland," long-term releases of contaminants due to changes in the physical and chemical equilibrium are predictably similar to what would occur in a completely upland site. However, control of these long-term releases is substantially more difficult at a nearshore than at an upland location. Additionally, it is inevitable that much of the soluble contaminant fractions will get back into the marine environment by diffusion and convection through and around the containment dike. One estimate is that most soluble contaminants would be lost from this type of site in one to two decades, if no control measures are used. The potential for adverse effects is greater in the nearshore than at an open-water location due to proximity to human activity and greater biological production.

3.04.04 Sediment-Bound Contaminants. These contaminants, especially those that are tightly bound, are relatively easy to handle. Removal of the sediments and solids (via dredging) removes the contaminants (chapter 2); disposal and confinement of the sediments confines the contaminants. Control of solids (especially fines and organic compounds) to maximize retention in the disposal area, and completely and sufficiently capping the site to prevent particle migration, solves the disposal problem. However, sediment-bound contaminants may change their binding over time as chemical and physical characteristics of the disposal site change.

a. Open-Water Disposal. Loss of sediment from the disposal site during placement of the contaminated material is the primary source of short-term release. As many contaminants are bound to the finer-grained sediments and these components are most easily lost during discharge, some release is inevitable. Discharge into quiet waters will minimize resuspension by currents and allow more rapid settling out of fines. Once the contaminated material is capped, maintaining the cap's integrity against erosion and bioturbation is sufficient to retain sediment-bound contaminants.

b. Upland Disposal. As with open-water disposal, the primary concern is control of solids. Mechanical dredging and direct placement of the sediments in the disposal site maximizes retention. For hydraulically dredged material, proper design of the disposal site and weir, including spur dikes, is important. The opportunity to further treat the effluent, including flocculation, makes this disposal method highly effective for solids. The principal loss of sediment-bound contaminants results from changes to physical and chemical parameters that cause sediment-bound contaminants to go into solution. Short of this phenomenon, minor leakage of sediment through the cap, dikes, or liners allowing release of contaminants is possible in some instances. Bioturbation and erosion represent the greatest source of solids loss.

c. Nearshore Disposal. This method has the same concerns and opportunities as upland disposal for the retention of sediment bound contaminants. Solids leakage through dikes must be routinely considered.

3.05 Disposal Sites. One of the tasks undertaken for this report was the identification and evaluation of potential disposal sites that could accept contaminated sediments from Commencement Bay. Selection of individual sites for further evaluation was based on criteria explained below. These sites are shown on plate 2.

The primary consideration was to locate potential disposal sites in proximity to the Commencement Bay Nearshore/Tideflats Superfund Site and ongoing or proposed navigation dredging areas. Thus, no sites outside of the Commencement

Bay area were identified for evaluation; off-site considerations and options are discussed briefly following the descriptions and evaluations of specific disposal sites.

The identification of sites was not exhaustive. The objective of the exercise was to determine, generally, whether capacity existed within a least cost, least disturbance, reconnaissance level of detail to accommodate the large volumes of contaminated sediments anticipated. To this end, a number of potential disposal sites for each disposal method were identified, resulting in a total capacity that is expected to exceed actual needs. Those sites that did not pass the initial screening criteria or are not recommended here should not be considered unacceptable for potential consideration; they are simply unnecessary or less desirable at this time.

3.05.01 Site Selection Criteria. Table 3-1 shows the criteria that were used to identify potential disposal sites for the three disposal methods discussed in the previous sections of this chapter. These criteria were selected based primarily on cost and equipment limitations.

TABLE 3-1

INITIAL SITE SELECTION CRITERIA

Disposal Method	Disposal Criteria
Open-Water	Distance: within 12 miles of waterways
Upland	Distance: within 2 miles of waterways Capacity:[1/] greater than 50,000 c.y. (sites below +20 feet MLLW) greater than 1,000,000 c.y. (sites at or above +20 feet MLLW) Other: absence of permanent development
Nearshore	Distance: within 12 miles of waterways Elevation: -35 feet to +20 feet MLLW Capacity: greater than 100,000 c.y.

[1/] Sites would be filled to either +20 feet MLLW or +35 feet MLLW.

Distance criteria were based on equipment limitations and cost considerations. It was assumed that large cutterhead pipeline dredges (22- to 36-inch) were the most likely candidates for hydraulic dredging. Dredges of this size would be able to pump typical Commencement Bay sediments about 2 miles on the level before a booster pump would be required. This distance is approximate and must be modified by elevation considerations. Thus, the hills to the north and south of Commencement Bay represent a limit to pipeline transport. The 12-mile distance criterion was selected as the farthest distance that a two-barge mechanical dredging operation can continuously accommodate (i.e., the dredge will fill one barge while the second is proceeding to the disposal site, dumping, and returning). Beyond 12 miles a three-barge operation would be necessary. In both cases, hydraulic or mechanical, adding booster pumps or another barge increases costs.

The distance criteria also relate directly to the elevation criteria, especially for consideration of upland sites. Filling of upland sites to +20 feet MLLW and to +35 feet MLLW were considered. For small sites (less than 40 acres and with less than 1 million c.y. capacity) final site elevation would be +20 feet MLLW. Filling above that elevation would remove the parcel from railroad access and could cause land use changes (e.g., change heavy industrial to light industrial use). Fill of one or more large sites to the maximum economical pumping height of +35 feet MLLW might provide bay-wide benefits to justify the tradeoff. For nearshore disposal, filling a site above +20 feet MLLW removes it from easy water access and reduce the site's potential for development.

Minimum site capacity was determined partially based on cost considerations. Although actual costs must be determined on a case-by-case basis, a site with at least 100,000 c.y. capacity would be of sufficient size to amortize development costs for treatment facilities and site preparation costs, and would provide sufficient area (about 40 acres) to encourage settling of solids. It was felt that larger sites of at least 1 million c.y. capacity represent long-term, multiple-use disposal opportunities rather than one-time uses. This opportunity for repeated use over time would imply a displacement, either potential or actual, of heavy industrial use of the site. Capacity for accepting at least 1 million c.y. of contaminated sediment has tangible economic inducements for long-range solutions to Commencement Bay Superfund and navigation issues.

Only sites that had no large-scale, permanent development or facilities in place were considered.

3.05.02 Open-Water Disposal Sites. Historically, there have been many unconfined, open-water disposal sites in Commencement Bay. While past studies have identified many of these former sites, an unknown number have never been identified (often one- or two-time occurrences that were never reported). This report considers three open-water sites located in Commencement Bay (figure 3-12). A brief description of each site is provided including a limited evaluation of the site's strengths and weaknesses. Acquisition costs for these sites were not investigated.

a. Puyallup River Delta Disposal Site.

(1) Description. This site is located 1/2-mile west of the mouth of the Puyallup River at latitude 47°,16',30", longitude 122°,26',00". Until 1972, it was the Department of Natural Resource's (DNR) designated open-water site; ownership remains with the State of Washington. The site occupies the

Puyallup River delta; surface radius of the former disposal site is 900 feet. Bottom elevation slopes from -28 feet MLLW to approximately -200 feet MLLW.

(2) Limitations. The site has a history of major slides from the delta into the deep water of Commencement Bay on about a 10-year frequency. Disposal of fine-grained sediments typical for Commencement Bay will increase the frequency of slides. Capping would be difficult and slides could re-expose the contaminated material. Because the area is active, benthic communities would be short lived. However, it is located within the migratory paths of salmonids moving to and from the Puyallup River system; and Indian commercial net fishing occurs. Disposal may have to avoid times when juvenile salmonids are present and special restrictions may be necessary during the fishing season. Because of its location on the delta, a large volume of uncontaminated material is available nearby at very low cost (dredging) which could be used to cap contaminated sediments. It may be possible to place the contaminated sediments at the edge of the slide zone where the continuing accretion could further bury them.

(3) Information Needs. Detailed geotechnical evaluations and environmental characterizations are necessary.

b. Department of Natural Resources (DNR) Disposal Site.

(1) Description. The site has been the DNR designated open-water site for Commencement Bay since 1972; it is located at latitude 47°,17',40" and longitude 122°,27',35", over 3 miles from the anticipated dredging sites. Surface radius of the site is 900 feet; depths are in excess of 500 feet. Bottom topography is nearly level. The site has been used regularly for dredged material disposal since its designation and is known to be contaminated by a variety of compounds.

(2) Limitations. The depth would make accurate placement of the contaminated material and cap within the limits of the designated area difficult. Monitoring would be similarly difficult. However, the site has the capacity to receive all acceptable dredged materials projected for the future of Commencement Bay. Since the site has been used regularly in the past, contaminant levels at the site are higher than background levels. Therefore, disposal of contaminated material at the DNR site may be expected to have a lesser biological impact than would disposal of contaminated material at an uncontaminated area. Also, the site's depth places it outside the feeding depths of salmonids and many commercial fishes.

(3) Information Needs. Bottom current energies should be defined. Limited geotechnical and environmental characterization may be needed. This site would require the least amount of new information for open-water sites.

c. Hylebos/Browns Point Disposal Site.

(1) Description. This site is located midway between the mouth of Hylebos Waterway and Browns Point at latitude 47°,17',40", longitude

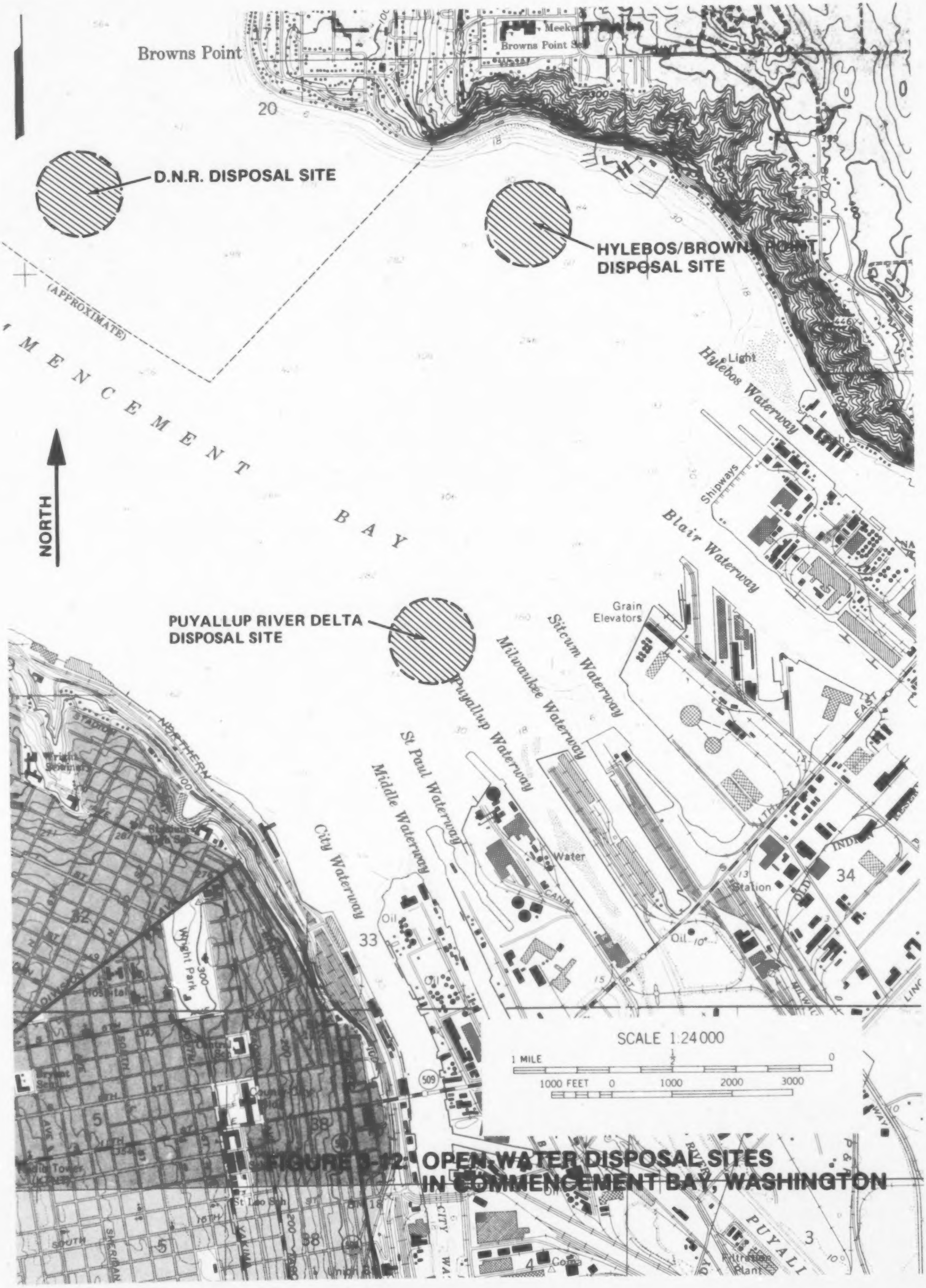


FIGURE 3-12: OPEN-WATER DISPOSAL SITES IN COMMENCEMENT BAY, WASHINGTON

122°,25',30". Depths range between 100 and 200 feet. The site is a natural, horseshoe-shaped depression; closing the fourth side with an underwater dike would provide capacity for over 2.5 million c.y. The site is within 2 miles of Hylebos, Blair, and Sitcum Waterways. Ownership is by the State of Washington.

(2) Limitations. Relatively little is known of the site, so extensive investigations may be required. Local fishermen indicate that the area is popular for bottom fishing though success is unknown. While the depth is outside the normal feeding range of salmonids, the Puyallup Tribe indicate that the upper water column is seasonally used by drift netters. As the site has not been previously used for disposal, aquatic resources may be undisturbed and possibly significant; use of the site would adversely affect these resources. However, past and present use of the water surface for extensive log booming may have affected the benthic community. Capacity of the site (2.5 million c.y.) is sufficient for many years of disposal, allowing incremental diking. Diking the open, fourth end would allow more complete containment of contaminated materials. This and the lesser depth (100 to 200 feet) would make capping and monitoring easier than at the existing DNR open-water site.

(3) Information Needs. As noted, least is known of this site. The site may be environmentally significant. Detailed investigations of all considerations (geotechnical, hydrology, environment) would be necessary.

3.05.03 Upland Sites. Seven upland sites located in the Commencement Bay area (figure 3-13) were considered. Site acquisition costs were not investigated. A brief description of each site is provided, including a limited evaluation of the site's strengths and weaknesses. Port of Tacoma Site No. 5, shown on the figure, has since undergone use for other purposes and it is not discussed here.

Concerns about upland disposal have been expressed by several parties. The Puyallup Tribe is concerned about the potential disposal of any contaminated materials within the boundaries of their reservation. The Tacoma/Pierce County Department of Public Health has questions about the effects that upland disposal of contaminated dredged material may have on ground water and drainage systems and the possible burial of hazardous materials already existing on the site. The Port of Tacoma is concerned about the loss of real estate potential should sites be filled above the normal industrial grade elevation (+20 feet MLLW); and the port's leasees may express concerns about locating on or near contaminated materials.

a. Puyallup Mitigation Site.

(1) Description. This site is located north of the Puyallup River and east of Lincoln Avenue, approximately 1 mile from Sitcum and Milwaukee Waterways, and 2 miles from the middle of Blair Waterway. Ownership is by the Port of Tacoma. The 40-acre site has been previously filled with dredged material and its current elevation is approximately +18 feet MLLW. Filling to

+35 feet MLLW is contemplated; this would provide about 1 million c.y. capacity. Vegetation has reestablished, otherwise the site is vacant. The existing fill could be used to construct containment dikes. The site is currently zoned S-10 (Port Industrial) by the city of Tacoma; however, it has been proposed as a wetland creation site by the port as mitigation for filling of site No. 5 for the Sea-Land terminal development (see figure 3-13). Slurry water from this site would be discharged into the Puyallup River.

(2) Limitations. Presently, this site is proposed as mitigation by excavating the site and breaching the Puyallup River dike to create freshwater wetlands. Presumably an alternative mitigation site would need to be located.

(3) Information Needs. At least general geotechnical and environmental information are or will be available due to the ongoing discussions on use of the site as a mitigation area. Detailed hydrologic studies may be necessary to determine potential ground water effects.

b. Port of Tacoma Site "D".

(1) Description. This 60-acre site is bounded by the Port of Tacoma Road on the northeast, the Union Pacific Railroad (UPRR) switchyard on the southeast, and Marshall Way on the northwest, within the area commonly known as the "Tacoma Tideflats." The site is a former dredged material disposal area and has been filled to approximately +16 feet MLLW. Filling of the site to +20 feet MLLW provides capacity of 100,000 c.y.; fill to +35 feet MLLW provides capacity of an additional 1,450,000 c.y. (total: 1,550,000 c.y.). The site is centrally located and within 1 mile from Hylebos, Blair, and Sitcum Waterways. Ownership is by the Port of Tacoma. The site is zoned S-10 (Port Industrial) by the city of Tacoma. The discharge path for this site is into the lower end of the Blair Waterway through an existing drainage canal.

(2) Limitations. The port has no current plans for developing the site and no prospective tenant, suggesting that the site may be available. Because the site has been filled in the recent past, its environmental value is judged relatively low.

(3) Information Needs. Because of its history of fill, detailed environmental investigations are probably unnecessary. Hydrologic and limited geotechnical information to determine potential ground water effects would be prudent.

c. Puyallup River/Railroad Site.

(1) Description. This site is located on the south side of Interstate 5 (I-5), upstream from the I-5/Puyallup River bridge, and is situated between the UPRR and the Puyallup River. It is approximately 2 miles from the heads of Blair and Hylebos Waterways. Present elevation is approximately +9 feet MLLW. Filling the +80-acre site to +20 feet MLLW provides capacity of 1.3 million c.y.; filling the site to +35 feet MLLW provides capacity for an additional 2 million c.y. (total: 3.3 million c.y.). One-third of the site

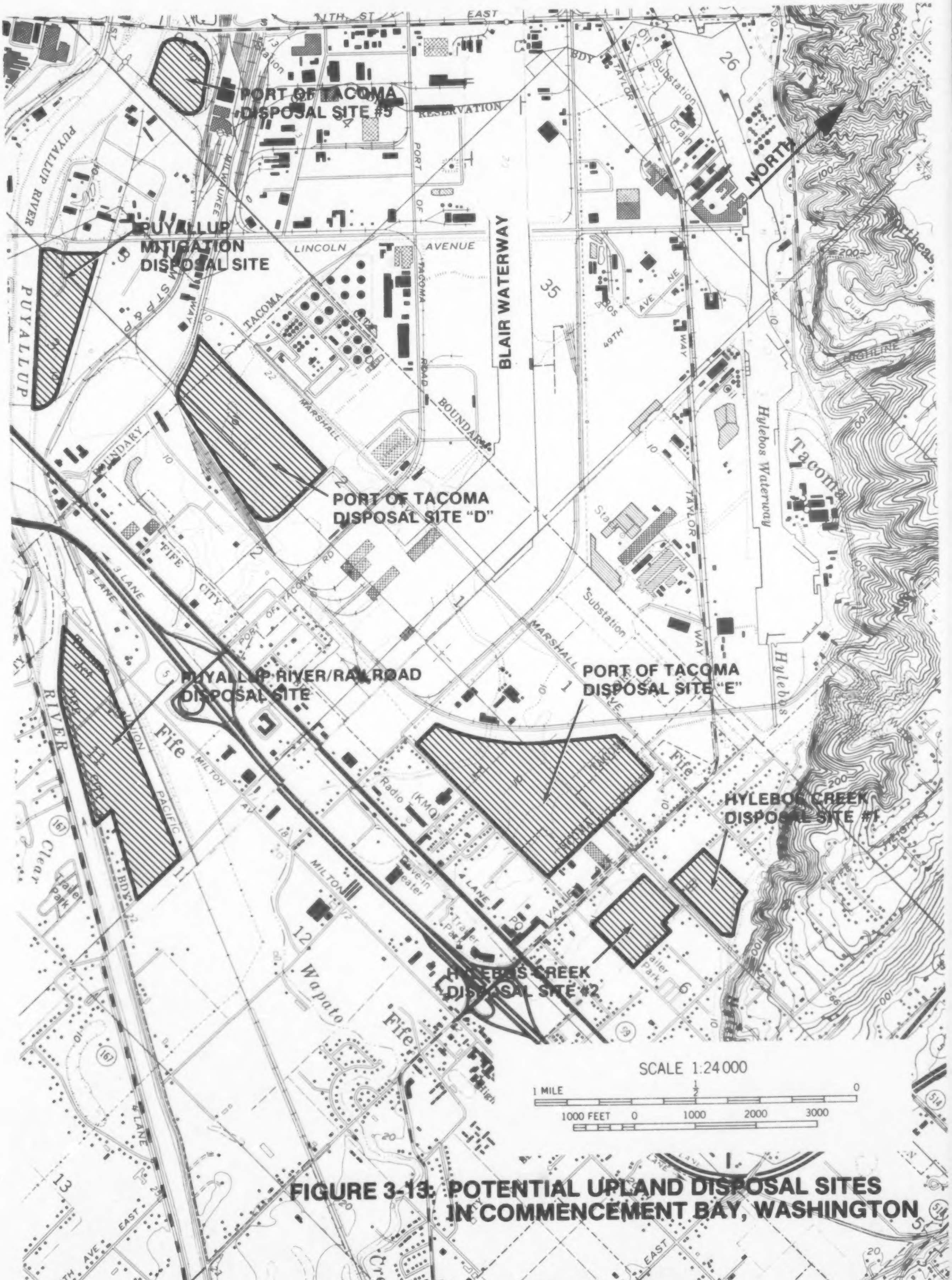

PORT OF TACOMA DISPOSAL SITE #5
PUYALLUP MITIGATION DISPOSAL SITE
PORT OF TACOMA DISPOSAL SITE "D"
PUYALLUP RIVER/RAILROAD DISPOSAL SITE
PORT OF TACOMA DISPOSAL SITE "E"
HYLEBOS CREEK DISPOSAL SITE #1
HYLEBOS CREEK DISPOSAL SITE #2
NORTH
BLAIR WATERWAY
Hylebos Waterway
LINCOLN AVENUE
PUYALLUP RIVER
Fife
Tacoma
SCALE 1:24 000
1 MILE
½
0
1000 FEET
0
1000
2000
3000

FIGURE 3-13: POTENTIAL UPLAND DISPOSAL SITES IN COMMENCEMENT BAY, WASHINGTON

3-30

has been identified as a wetland pasture; the remainder is under agricultural cultivation. Ownership is by the UPRR, although the former, meandering river channel through the site is claimed by the Puyallup Tribe. The site is zoned M-2 (Light Manufacturing) by the city of Fife. Water from the site would be discharged into the Puyallup River.

(2) Limitations. The site has very large capacity, even without filling to +35 feet MLLW. Fill would also eliminate approximately 25 acres of freshwater wetlands.

(3) Information Needs. Little is known about this site. Detailed hydrological, geotechnical, and environmental investigations would be necessary. Availability of the site is also unknown.

d. Port of Tacoma Site "E".

(1) Description. This site is located southeast of the head of Blair Waterway and adjacent to the Tacoma Throughway. It is bounded by Word Road to the south and Franck Road to the east. The site is within 1 mile from Blair and Hylebos Waterways and has been used for dredged material disposal in the recent past. Current elevation of the 71-acre site is +20 feet MLLW. Capacity for fill to +35 feet MLLW is 1.7 million c.y. The site is owned by the Port of Tacoma and zoned S-10 (Port Industrial) by the city of Tacoma. At the present time, the port has no tenant or plans to develop the site. The discharge path for this site would be through the existing drainage channel and creek and into the lower end of the Hylebos Waterway.

(2) Limitations. Filling the site would raise it above normal industrial level and reduce its land use value. As the site is only sparsely vegetated, its environmental value is judged to be relatively low.

(3) Information Needs. Same as Port of Tacoma Site "D".

e. Hylebos Creek Sites Nos. 1 and 2.

(1) Description. These two sites are located east of 54th Avenue East on the north and south sides of 8th Street. Both sites lie within 1 mile of the head of Blair and Hylebos Waterways. Both sites are at approximately +9 feet MLLW; site No. 1, to the north of 8th Street, is 25 acres and site No. 2, to the south, is 20 acres. Filled to +20 feet MLLW, capacity of site No. 1 is 450,000 c.y. and site No. 2 is 325,000 c.y. for a total capacity of 775,000 c.y. Filling both sites to +35 feet MLLW would generate an additional 1 million c.y. capacity. The two sites are under multiple ownership and have been zoned A-1 (Manufacturing) by Pierce County. The two sites are presently being cultivated for agriculture. The discharge path from these sites would be either into the small creek that runs between the sites and the hill to the west or via a new channel that connects with the existing drainage channel for disposal site "E".

(2) Limitations. The two sites provide an ideal opportunity to use a two-cell disposal and treatment system. Dredged material could be hydraulically deposited into the first cell and the return effluent treated in the second cell. Hylebos Creek is located adjacent to the northern site and could receive the treated effluent. Use of the two sites would substantially alter existing land use. Availability is unknown.

(3) Information Needs. Similar to the Puyallup River/Railroad site.

3.05.04 Nearshore Sites. Nearshore sites are all located along or within Tacoma Harbor waterways. This report considers six nearshore sites located in Commencement Bay (figure 3-14). A brief description of each site is provided that includes a limited evaluation of the site's strengths and weaknesses.

Material placed in these disposal sites will eventually form two distinct layers. Fill placed below the higher tide elevations will remain saturated at all times due to ground water, marine water intrusion, and precipitation, whereas the material above this elevation will drain and become seasonally or permanently dry. Thus, nearshore disposal offers some option in placing material that should remain saturated or unsaturated. Capacities for these sites are expressed as two figures: the first figure provides capacity of the site from its existing elevation to the approximate mean high tide elevation in Commencement Bay (+12 feet MLLW); the second figure indicates capacity of the site between +12 and +18 feet MLLW. At least 2 feet of cap was assumed to bring the sites to industrial elevation.

Generic problems with nearshore disposal have been discussed earlier in this chapter. Environmental effects (particularly to salmonid resources) are potentially severe and normally require mitigation.

Testing of existing shoaled material may be necessary to assure that no hazardous waste is buried. Treatment and monitoring could be difficult and perhaps impossible for some contaminants. Discharge pathways for all sites would be into the adjacent waterway.

a. Middle Waterway Site.

(1) Description. Middle Waterway is located between City Waterway to the south and St. Paul Waterway to the north. The waterway has shoaled into the intertidal range at its inner end and is quite shallow throughout with an average elevation of -7 feet MLLW; although medium draft tugboats are still able to utilize the outer third of the waterway. The 27-acre site has a total capacity of 650,000 c.y., of which 390,000 c.y. would be "wet" (below +12 feet MLLW) and 260,000 c.y. would be "dry." Users and adjacent landowners include Foss Towing, UPRR, St. Regis Paper Company, Paxport Mills, and others. Foss has indicated a desire to stay or to maintain its moorage at the outer end of the waterway. Paxport Mills, under recent Federal permit action, has placed a small fill along the waterway; mitigation of a resulting wetland loss was a condition of the permit. Ownership of the waterway is with the State of Washington.

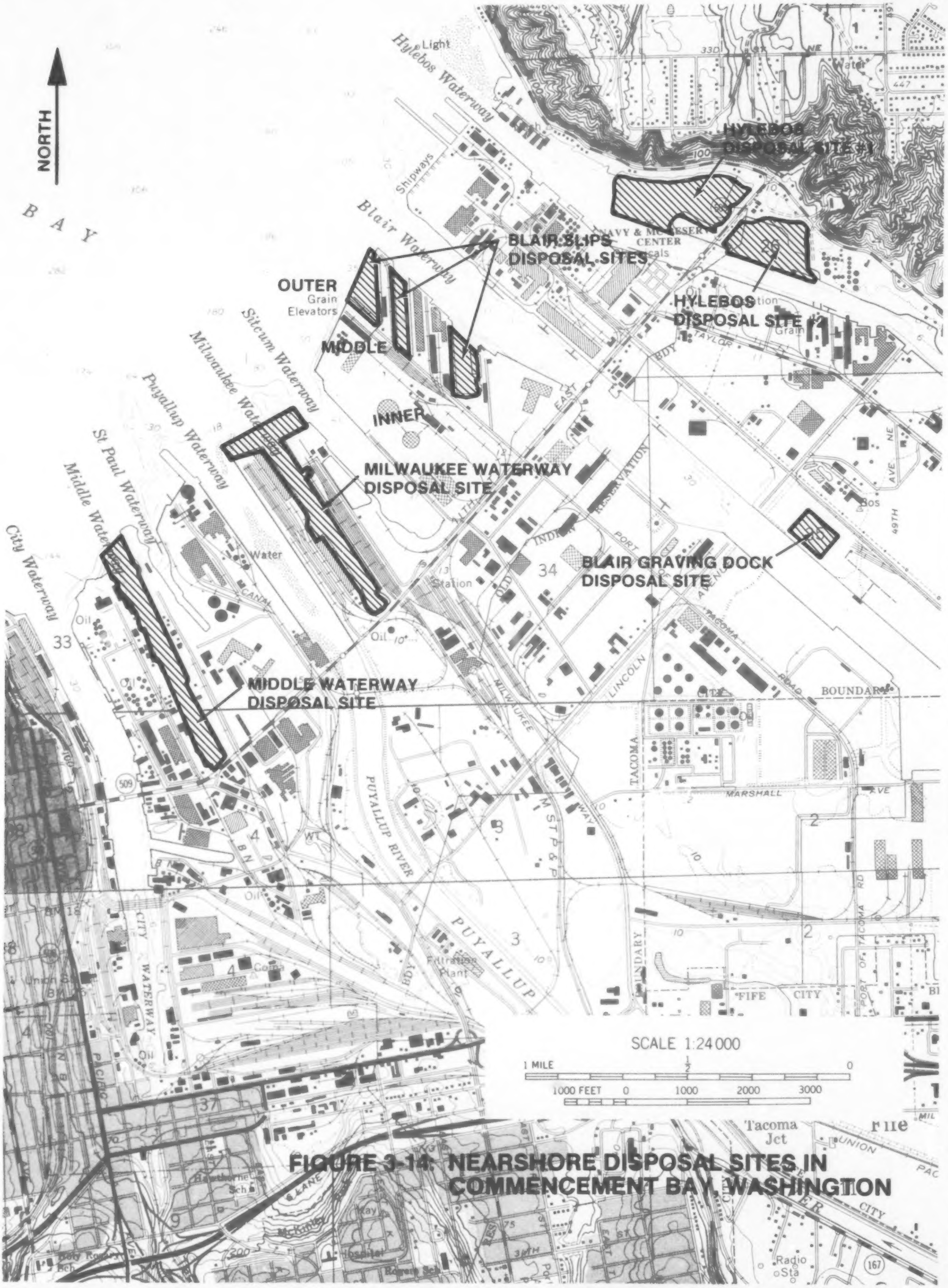


FIGURE 3-14: NEARSHORE DISPOSAL SITES IN COMMENCEMENT BAY, WASHINGTON

(2) Limitations. Although the waterway is somewhat in decline, it is still a working waterway. Filling would adversely affect those businesses and industries along the waterway that still rely on water transportation for part or all of their operation. The site would be able to accept materials dredged by any method.

(3) Information Needs. A variety of environmental information will be necessary to determine adverse effects. Detailed geotechnical and hydrology information will be needed to design containment dikes.

b. Milwaukee Waterway Site.

(1) Description. Milwaukee Waterway is located between the Puyallup River to the south and Sitcum Waterway to the north. Average site elevation is -26 feet MLLW and the waterway covers approximately 30 acres. Wet capacity is estimated at 1,870,000 c.y.; dry capacity is 290,000 c.y.; total is 2,160,000 c.y. The site has been recently acquired by the Port of Tacoma who has filed a permit application (PN 071-OYB-2-006175) to fill the waterway to accomodate Sea-Land's operations and to develop a container terminal facility. Although the waterway has been used by deep-draft navigation in the past, such use in recent years has been infrequent. The waterway is also the primary disposal site for the Corps of Engineers' proposed navigation improvements project for Blair and Sitcum Waterways. The site is zoned S-10 (Port Industrial) by the city of Tacoma. Contaminated materials are suspected to exist within the waterway.

(2) Limitations. The port would prefer to develop this site in the near future (2 years) rather than wait for Superfund results or for authorization of the Corps of Engineers' navigation improvements project. Otherwise, limitations are virtually identical to Middle Waterway; although there are currently fewer users of Milwaukee Waterway as a navigation waterway.

(3) Information Needs. Environmental descriptions and impacts information is being developed for a Federal environmental impact statement to evaluate the port's permit application.

c. Blair Waterway Slips.

(1) Description. The three slips are located on the south side of Blair Waterway at the outer end. The outer and middle slips are used for deep-draft navigation; the inner slip is presently used for shallow draft moorage by commercial fishing vessels. The outer slip is owned by the State of Washington and the middle and inner slips are owned by the Port of Tacoma. The area is zoned S-10 (Port Industrial) by the City of Tacoma.

Average elevation of the 7-acre outer slip is -30 feet MLLW. The slip lies bayward of Pier No. 1 and would have to be diked along Commencement Bay. Total capacity is 892,000 c.y., 825,000 c.y. wet and 67,000 c.y. dry.

The 8-acre middle slip lies between Piers No. 1 and 2 and has an average elevation of -30 feet MLLW. Total capacity is 945,000 c.y., 868,000 c.y. wet and 77,000 c.y. dry.

The inner slip is 12 acres and has an average elevation of -13 feet MLLW. Total capacity for the slip is 600,000 c.y., 484,000 c.y. wet and 116,000 c.y. dry.

(2) Limitations. The Port of Tacoma plans to fill these slips in the long term; however, at present they have no immediate need to fill the outer or middle slips. The port would like to fill the inner slip and had an approved Federal permit (issued in 1974, but currently expired) for this action. A condition of the permit required relocating the fishing fleet and the port was unable to meet this condition. The port has indicated that they would prefer to see any filling completed in a relatively short time frame to maximize the industrial use of the site. The multiple sites provide for large capacity and allow a multiple cell system for effluent treatment. The area is heavily industrial, however, and lengthy filling could disrupt ongoing uses. The outer and middle slips would require dikes approximately 48 feet high. Construction of such structures would probably require staged construction over at least 2 years. Filling of the inner slip would displace the existing fishing fleet.

(3) Information Needs. Similar to Middle Waterway site.

d. Blair Graving Dock.

(1) Description. The site is located on the north side of Blair Waterway approximately 1,000 feet east of Lincoln Avenue. The site was excavated to -5 feet MLLW and used to construct the pontoons for the rebuilt Hood Canal Floating Bridge. The 700-foot by 500-foot rectangular site has a 200-foot-long opening onto Blair Waterway. Total capacity is 200,000 c.y., 136,000 c.y. wet and 64,000 c.y. dry. The site is owned by the Port of Tacoma and is currently under lease to the J.A. Jones Company; the lease expires in January 1986, at which time the port has the option of requiring the leasee to refill the site or to leave it as is. Zoning is S-10 (Port Industrial) by the city of Tacoma.

(2) Limitations. Filling of this site would displace the graving dock function from the bay.

(3) Information Needs. Geotechnical and hydrologic information is needed. It is unlikely that extensive environmental studies will be necessary.

e. Hylebos Waterway No. 1.

(1) Description. The site is located on the north side of Hylebos Waterway, immediately west of the East 11th Street Bridge, and is bordered to the north by Marine View Drive. Average elevation over the 74-acre area is -10 feet MLLW; however, the site is a combination of subtidal and intertidal

habitats containing the last tidal marsh in Commencement Bay. The site was the subject of a previous Federal permit application (PN 071-OYB-1-001200) that was withdrawn in 1978. Total capacity is calculated at 1,274,000 c.y., of which 550,000 c.y. would be wet and 724,000 c.y. would be dry. The site is owned by the Port of Tacoma and is zoned S-11 (Industrial) by the city of Tacoma.

(2) Limitations. Strong objections to filling of this wetland are expected from the Puyallup Tribe and environmental agencies and interest groups. Mitigation for the loss would be difficult.

(3) Information Needs. Similar to Middle Waterway. Environmental investigations on salmonid use and importance could be extensive.

f. Hylebos Waterway No. 2.

(1) Description. This site is located in the same approximate area as Hylebos Waterway No. 1 but is east of the bridge and inside the waterway. The site is bordered by Marine View Drive to the north and the Sound Refining Company to the east. Like Hylebos Waterway No. 1, the area is a combination of subtidal and intertidal, sloping northward from the waterway to high ground along Marine View Drive, and is presently being used for log storage. Capacity of the 24-acre site totals 300,000 c.y., approximately 70,000 c.y. wet and 230,000 c.y. dry. The site is owned by the Sound Refining Company, which has held meetings in anticipation of filing for necessary permits to fill the site for plant expansion. The site is zoned S-11 (Industrial) by the city of Tacoma.

(2) Limitations. Same as Hylebos Waterway No. 1.

(3) Information Needs. Same as Hylebos Waterway No. 1.

3.05.05 Off-site Options. Off-site disposal would involve use of one of the three disposal methods (open water, upland, or nearshore) at sites located outside of the Commencement Bay area. The differences between local and off-site disposal involve increased costs for transportation of the contaminated materials to the off-site disposal area and the problems of retaining the contaminants during that transport. The latter problem can be effectively handled by current technologies associated with transportation of hazardous materials; it is, however, expensive. The most common forms of long distance transport of dredged material would be barges, trucks, and railcars. All of these carriers could be made watertight or the material dewatered and then loaded. The potential for release of contaminants is increased, however, by this rehandling. The increased costs would depend upon the transportation mode selected and associated controls and treatments required. Barging of dredged material to an open-water site outside of the Commencement Bay area was considered initially, but was dropped because no likely specific site could be identified based on existing information.

Off-site disposal would seem to be justified only if at least one of the following criteria were met:

- No local disposal options were available that could accommodate either the volume or degree of contamination of sediments dredged.
- A regional disposal site and protocol existed for contaminated sediment.
- The material contained contaminant fractions that require treatment that is not available locally.
- Local public and/or political pressures rendered local disposal of contaminated sediments impossible.

CHAPTER 4.0 SITE CONTROL AND TREATMENT PRACTICES

4.01 Introduction. Conventional site control and treatment measures are typically applied to and designed for a specific disposal site after dredging and disposal methods have been selected. The purpose of these measures is to ensure that material loss from a disposal site meets applicable environmental criteria. For contaminated materials, site control and treatment requirements can represent a controlling cost factor that must be considered prior to selection of the dredge and disposal site for a given job.

Site control measures addressed in this chapter all pertain to contaminant confinement within a selected area and isolation from the environment during and after disposal of contaminated sediments. Treatment practices include those physical, chemical, or biological processes that can be applied to contaminants in either the sediment-bound (solids), soluble, or gaseous phase resulting from the disposal of contaminated dredged material in open-water, nearshore, or upland disposal sites. In addition to site control and treatment, discussions are presented on biological control of disposal areas and appropriate monitoring requirements for each disposal method, as well as remedial response to monitoring indications. A summary of the site control and treatment alternatives is presented in chapter 6 in order of increasing degree or level of total contaminant removal. This hierarchical approach allows the decisionmaker to view varying levels of control with respect to overall degree of protection afforded and effects of increasing degrees of protection on costs.

4.02 Site Controls for Disposal.

4.02.01 Overview. Potential impacts resulting from loss of contaminants during and after dredging and disposal operations may require that certain physical or chemical controls be used for open-water, nearshore, and upland disposal sites. Controls are containment techniques, and typically include lining with soil or synthetic membranes, capping, or cover and run on control operations; physical and chemical stabilization of contaminated materials to minimize escape of contaminants; and collection, dewatering, and treatment of effluent, runoff, and leachate. Not all of the measures apply to each disposal site; however, common practices include capping and lining operations. Since many control and treatment measures are similar for nearshore and upland disposal sites, these disposal alternatives will be discussed together below.

4.02.02 Controls for Open-Water Disposal. Feasible options available for implementing open-water disposal with controls include submerging the discharge (submerged diffuser shown in figure 3-2), confining the dredged material subaqueously (submerged dikes shown in figures 3-5 and 3-6), and capping the dredged material subaqueously (figure 4-1). All of these controls can be considered to be a part of the capping control option. Placement of contaminated sediments and cap materials is discussed in chapter 3. Types of capping materials and stability of the cap are discussed below.

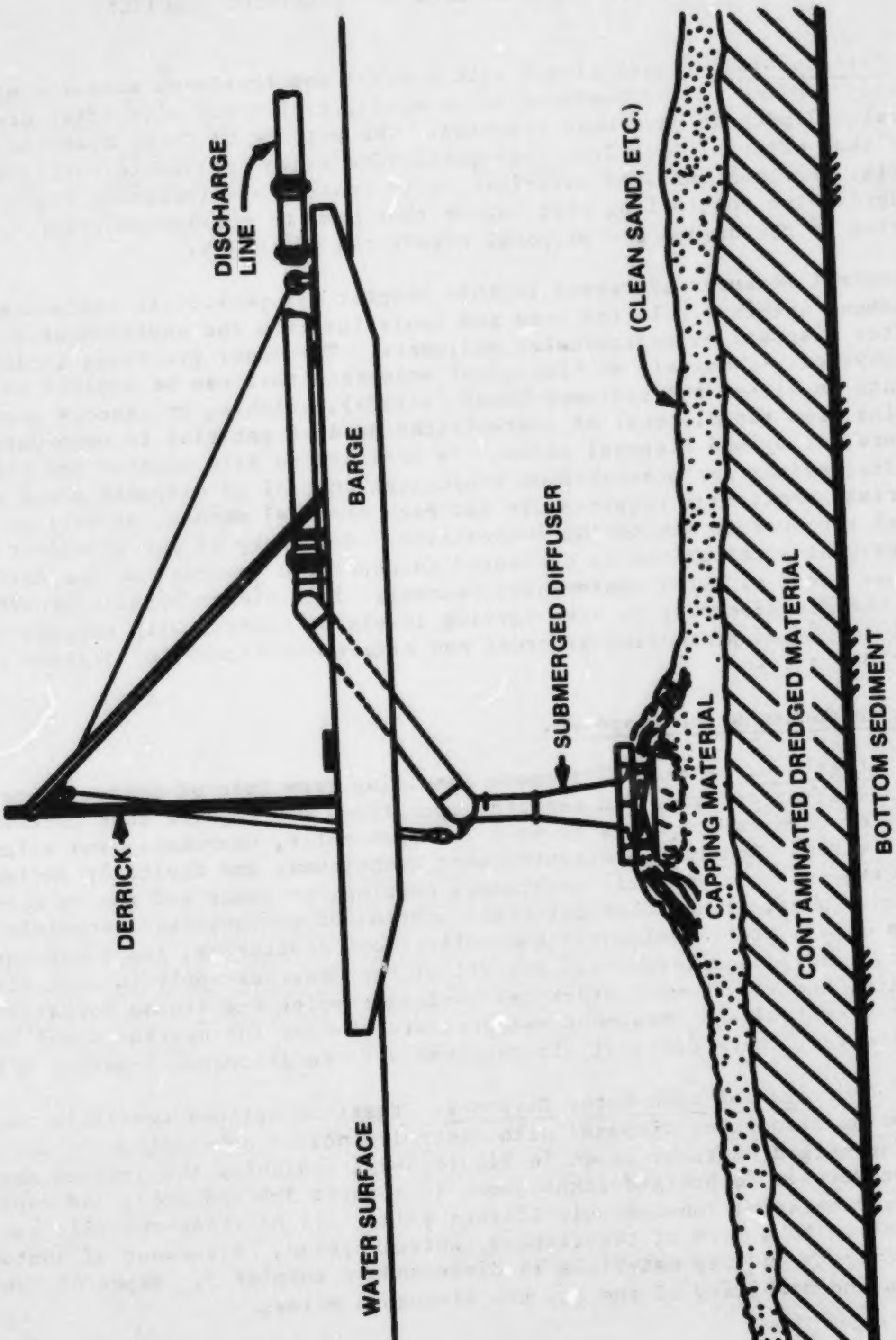


Figure 4-1: Capping With Submerged Diffuser

a. Capping Materials. There has been a significant amount of research devoted to cover materials for burial of hazardous spills in lakes and waterways. This research, summarized by Hand, et al. (1978), also applies to capping contaminated dredged material. Materials, both naturally occurring and manmade, that can be used to cover contaminated dredged material are divided into three categories: inert, chemically active, and sealing agents. Of these, only inert materials are likely to be successfully used in Commencement Bay.

Inert materials include coarse- and fine-grained soils. Research is being performed at the WES to determine covering depths required to inhibit bioturbation of the contaminated materials and to retard leaching of contaminants into the water column. When soils are used as capping materials they should be thick enough to protect the underlying deposit from disturbances caused by storm generated waves, propeller wash from navigation traffic, and to bury the contaminated sediments out of the reach of benthic organisms. The nature of the capping material will influence the depth and character of burrowing. Myers (1979) reported that a sand cap will attract suspension feeding organisms that should not be expected to be deep burrowers, while deep burrowing deposit feeders will colonize a fine-grained cap. Therefore, site-specific biological populations (such as the deep-burrowing geoduck clam) are important in designing the cap thickness. Bokunieweiz (1981) reported that for disposal sites in relatively protected, nearshore waters, a cap thickness of less than a meter should be sufficient, but site-specific studies should be done to evaluate biological populations and erosion potential.

Capping with chemically active materials involves the placement of a chemical compound over the contaminated dredged material that would react with the contaminants to neutralize or otherwise decrease toxicity. This strategy differs from the use of inert materials in that each contaminated dredged material must be dealt with on a case-by-case basis. Carbon compounds are a common example of chemically active ingredients that can be added to a cap. In the capping of dredged material, the active material should be combined with an inert stabilizer to provide stability to the cap. Another approach would be to cover the active covering layer with an erosion-resistant inert layer. The inert layer would also provide protection for the benthic organisms. While the inert covers have little or no chemically related impact on the organisms, the chemically active covering agents could be harmful to some organisms. Also, greater accuracy would be required for placement of the chemically active materials.

Sealing agents include grout, cements, and polymer films. The unique feature of the grouts and cements is that, when placed on top of contaminanted sediments, they will harden and form a crust, preventing erosion and resuspension of the contaminated material. A Japanese firm (Takenaka Komuten, 1976) has done work in dredged material stabilization and deep mixing of sediments using grouting compounds. Also, grouting is often used in the offshore oil industry for stabilization of oil producing facilities. The technology for using grout in the saltwater environment is well developed and it could be adapted for use in capping contaminated dredged material. However, there are some disadvantages associated with the use of grout in capping dredged material. The thin layer of grout placed over the contaminated material cannot be considered as a permanent cap material. It should be used with a covering of inert material to provide additional stability and habitat for benthic organisms. There could also be problems with the grout cracking as the contaminated dredged material consolidates with time.

Polymer film systems have been the subject of a report by Widman and Epstein (1972). They proposed barge mounted deployment systems for either hot or cold application of polymer film overlays. The application systems included those for placing coagulable polymers, hot melt materials, and preformed commercially available films. The application system for the preformed overlay limited its application to water depths of 25 to 30 feet. Roe, et al. (1970), reported on a chemical overlay system which included 2,000-square feet per hour coverage and availability for water depths up to 120 feet. Concepts for the use of polymer film overlays for cover of contaminated dredged material were developed from early erosion control efforts related to marine salvage work. None of the concepts have been field tested for dredged material. The major limitation to these concepts involves the design, construction, and cost of capital equipment required to place them.

Capping is currently being carried out in the Long Island Sound and New York Bight as a means of controlling the potential harm of contaminated or otherwise unacceptable sediments. All of these capping projects have used inert natural materials for covering the contaminated sediments. A significant amount of research has been performed on stability and biological activity of inert cap materials (Bokuniewiez, et al., 1981; Freeland, et al., 1983; Morton, 1983; O'Conner, 1983; Brannon, et al., 1983). Based on these past experiences, capping using only inert materials in Commencement Bay is considered to be a feasible treatment alternative for some of the contaminated sediments. Costs for inert capping are discussed in chapter 5.

b. Stability of Capping Materials. Stability of the capping material is a major concern in the design of capping projects. Factors influencing cap erosion include: (1) the particles (size, uniformity, shape, size distribution, texture, etc.); (2) the hydrodynamics of the system; (3) slope of the mound; and (4) the degree of cap material cohesiveness. Therefore, the prediction of erosion potential of a capping material should be made on the basis of site specific data. The inert materials used for capping can be classified as cohesive or noncohesive. For given erosive forces, movement of noncohesive particles depends on shape, size, and density of discrete particles and on the relative position of the particle with respect to surrounding particles. The movement of cohesive particles depends on those factors cited above for noncohesive particles as well as on the strength of the cohesive bond between particles. This latter resisting force can be much more important than the influence of the characteristics of the individual particles. Cohesive capping materials excavated by mechanical dredges will be more resistant to erosion than those excavated by hydraulic dredges. Once the cohesive bond has been broken during the hydraulic dredging process, the individual particles and flocs behave essentially as noncohesive particles until they gain strength through the consolidation process. The degree of consolidation, which is inversely proportional to the interstitial water content, has a significant effect on the ease at which the fine-grained particles will erode. The time required for the complete consolidation of fine-grained capping material will be many years if the material is predominantly clay.

A problem with capping in underwater sites is the difficulty of assessing the dispersion of the contaminated mass to be covered by the cap. Contaminated materials placed in an open-water site without the use of an underwater diffuser may be spread over a wide area by stratification of the water column from thermoclines or currents, or by bottom currents. Fine particles, to which most of the bound contaminants are attached, are the most likely to be distributed over a wide area. Postdisposal sampling of the area for contaminant distribution would probably be necessary for level bottom open-water disposal.

Another problem with underwater capping is the potential for displacement of the contaminated mass by capping. Depending upon substrate firmness and the density of the contaminated mass, the cap material may displace and redistribute the contaminated materials, especially if the capping material is of a higher density or coarser size than the contaminated material. Determination of the potential for mass failure and dispersion would require testing with materials physically similar to those which will be placed underwater.

4.02.03 Controls for Upland and Nearshore Disposal.

a. Background. Diked upland and nearshore containment areas are used to retain dredged material solids while allowing the carrier water or entrained water to be released from the containment area. This section discusses appropriate controls that can be applied to the containment of contaminants in nearshore and upland disposal sites.

b. Liners. A variety of liner materials are available for use in confined disposal operations. Principal characteristics, advantages, and disadvantages of liners and flexible membranes are listed in table 4-1. Soil liners are expected to be the only liner necessary for most disposal of dredged material at upland and nearshore sites. However, in certain upland applications, a combination of synthetic membrane and soil liner may be required to achieve maximum containment of contaminants. To ensure continued effectiveness of the liners, whether soil or flexible membrane, they must be compatible with the dredged material and leachate they are to contain and be properly installed.

(1) Soil Liners. Soil liners are generally adequate for most dredged material disposal sites and are recommended for use on the sides and bottom of upland areas containing contaminated material. In general, clay is a good liner material that is not only relatively inert to chemical attack but will also act as a filter, absorbing many contaminants from the leachate (Kelley, 1982). Unfortunately, the chemical compatibility of clay soils with leachate

Liner material	Characteristics	Range of costs[a]	Advantages	Disadvantages
Soils:				
Compacted clay soils	Compacted mixture of onsite soils to a permeability of 10^{-7}cm/sec	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Soil-bentonite	Compacted mixture of onsite soil, water and bentonite	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Admixes:				
Asphalt-concrete	Mixtures of asphalt cement and high quality mineral aggregate	M	Resistant to water and effects of weather extremes; stable on side slopes; resistant to acids, bases, and inorganic salts	Not resistant to organic solvents; partially or wholly soluble in hydrocarbons; does not have good resistance to inorganic chemicals; high gas permeability
Asphalt-membrane	Core layer of blown asphalt blended with mineral fillers and reinforcing fibers	M	Flexible enough to conform to irregularities in subgrade; resistant to acids, bases, and inorganic salts	Ages rapidly in hot climates; not resistant to organic solvents, particularly hydrocarbons
Soil asphalt	Compacted mixture of asphalt, water, and selected in-place soils	L	Resistant to acids, bases, and salts	Not resistant to organic solvents, particularly hydrocarbons
Soil cement	Compacted mixture of Portland cement, water, and selected in-place soils	L	Good weathering in wet-dry/freeze-thaw cycles; can resist moderate amount of alkali, organics and inorganic salts	Degraded by highly acidic environments
Polymeric membranes:				
Butyl rubber	Copolymer of isobutylene with small amounts of isoprene	M	Low gas and water vapor permeability; thermal stability; only slightly affected by oxygenated solvents and other polar liquids	Highly swollen by hydrocarbon solvents and petroleum oils; difficult to seam and repair
Chlorinated polyethylene	Produced by chemical reaction between chlorine and high density polyethylene	M	Good tensile strength and elongation strength; resistant to many inorganics	Will swell in presence of aromatic hydrocarbons and oils
Chlorosulfonate polyethylene	Family of poimers prepared by reacting polyethylene with chlorine and sulfur dioxide	H	Good resistance to ozone, heat, acids, and alkalis	Tends to harden on aging; low tensile strength; tendency to shrink from exposure to sunlight; poor resistance to oil
Elasticized polyolefins	Blend of rubbery and crystalline polyolefins	L	Low density; highly resistant to weathering, alkalis, and acids	Difficulties with low temperatures and oils
Epichlorohydrin rubbers	Saturated high molecular weight, aliphatic polethers with chloromethyl side chains	M	Good tensile and teat strength; thermal stability; low rate of gas and vapor permeability; resistant to ozone and weathering; resistant to hydrocarbons, solvents, fuels, and oils	None reported
Ethylene propylene rubber	Family of terpolymers of ethylene, propylene, and nonconjugated hydrocarbon	M	Resistant to dilute concentrations of acids, alkalis, silicates, phosphates and brine; tolerates extreme temperatures; flexible at low temperatures; excellent resistance to weather and ultraviolet exposure	Not recommended for petroleum solvents or halogenated solvents
Neoprene	Synthetic rubber based on chloroprene	H	Resistant to oils, weathering, ozone and ultraviolet radiation; resistant to puncture, abrasion, and mechanical damage	None reported
Polyethylene	Thermoplastic polymer based on ethylene	L	Superior resistance to oils, solvents, and permeation by water vapor and gases	Not recommended for exposure to weathering and ultraviolet light conditions
Polyvinyl chloride	Produced in roll form in various widths and thicknesses; polymerization of vinyl chloride monomer	L	Good resistance to inorganics; good tensile, elongation, puncture, and abrasion resistant properties; wide ranges of physical properties	Attacked by many organics, including hydrocarbons, solvents and oils; not recommended for exposure to weathering and ultraviolet light conditions
Thermoplastic elastomers	Relatively new class of polymeric materials ranging from highly polar to nonpolar	M	Excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to weathering and ozone	None reported

[a] L – $1 to $4 installed costs per sq. yd. in 1981 dollars; M – $4 to $8 per sq. yd.; H – $8 to $12 per sq. yd.

SOURCE: "Comparative Evaluation of Incinerators and Landfills," prepared for the Chemical manufacturers association, by Engineering Science, McLean, Va., May 1982.

Table 4-1: Summary of Liner Types

is based on limited data and experience; particularly for dredged material. Both organic and inorganic acids and bases may solubilize portions of the clay structure. The results of compatibility testing of clay with different organic and inorganic fluids have indicated the need not only for more laboratory testing, but also a need for fieldwork to determine validity of the generalizations obtained from previous hazardous waste studies (Green, 1983). Construction of soil liners to achieve remolded permeability of 1×10^{-7} cm/sec or less is recommended. The soil may be obtained onsite, from selected borrow areas, or from off-site sources. If available soils do not have the required low permeability, they can be blended with clay soils, bentonite, or other additives. Prepared bentonite formulations would probably be required for Commencement Bay sediments due to high salt content. Soil liners placed in a minimum 3-foot-thick layer are recommended.

(2) Flexible Membrane Liners. Synthetic membrane technology is new and a variety of synthetic materials and compounds are being manufactured, tested, and marketed. The various membranes being produced vary not only in physical and chemical properties but also in installation procedures, costs, and chemical compatibility with waste fluids. The liners range in thickness from 20 mil to 140 mil and are made from polymers of rubber, plastics such as PVC, polyolefins, and thermoplastic elastomers.

Since the prime purpose of the liner is to prevent leachate from escaping the disposal site, the physical integrity and chemical compatibility of the liner with the leachate must be ensured. Potential incompatible combinations of wastes and liners include the following:

- Polyvinyl chloride (PVC) tends to be dissolved by chlorinated solvents.
- Chlorosulfonated polyethylene can be dissolved by aromatic hydrocarbons.
- Asphaltic materials may dissolve in oily wastes.
- Concrete and lime based materials are dissolved by acids.

Expected life of synthetic liners is less than 30 years. In general, most polymeric material will tend to swell when exposed to fluids. Cross linking or vulcanizing a polymer or rubber will reduce its ability to swell in a solvent. Swelling usually has adverse effects on a polymer material. Some of the major effects of swelling are:

- softening,
- loss of tensile and mechanical strength and elongation,
- increased permeability and potential for creep, and
- increased susceptibility to polymer degradation.

Synthetic membranes are also subject to biological and ultraviolet light degradation.

(3) Limitations. Because there is currently no adequate method for successfully placing impermeable synthetic liners underwater, lining of nearshore sites is limited to the use of a soil liner. The material would be placed as a high density slurry layer and allowed to settle and consolidate. In upland sites, soil liners if allowed to dry would crack and lose integrity. Soil liners are subject to differential settlement and bioturbation prior to filling. Liner life will be highly site specific. Once exchangeable adsorption sites are filled within the liner, soluble contaminants will slowly migrate through the liner by diffusion.

Synthetic membrane liners are applicable only to the upland sites. They cannot be installed in areas of tidal influence or high ground water table. Synthetic liners are subject to leaks at field jointed seams, need physical protection, and are not self sealing if punctured. Physical and chemical integrity is highly site specific and dependent upon liner compatibility with dredged material and leachate.

c. Covers and Run On Control. Surface capping or covering in upland or nearshore sites is the placement of clean, low permeability material, usually 3 feet thick, over the confined dredged material. Surface capping is placed over the site to:

- reduce surface water run on,
- reduce surface water infiltration,
- reduce water erosion,
- reduce wind erosion and fugitive dust emission,
- contain and control gases and odors,
- provide a surface for vegetation and other postclosure uses, and
- prevent direct bioturbation (human and animal).

Covering of the material in upland and nearshore sites will be required intermittently (at end of each dredging cycle) and at final site closure. Various low permeable materials may be used, including soils and clays, admixtures (e.g., asphalt concrete, soil cement), and polymeric membranes (e.g., rubber and plastic linings). Typical final covers are composed of several layers. Run on control is also possible through barriers constructed on the high-ground side of the site.

(1) Cover Types. Two examples of layered cover systems are shown in figure 4-2 and the function of each layer is shown in table 4-2. A gravel layer or structure to break capillary pumping of moisture from the dredged material should be included to reduce upward migration of contaminants through the cap and surfacing of contaminated water as runoff. This biobarrier will also reduce cap penetration by roots of cover vegetation and by burrowing animals.

TABLE 4-2

PRIMARY FUNCTION OF COVER LAYERS

Layer	Reduce Run On and Infiltration	Reduce Water Erosion	Reduce Wind Erosion/ Dust Emissions	Control Gases and Odors	Provide Surface For Vegetation	Enhance Cover Integrity
Barrier	X			X		
Buffer						X
Filter						X
Gas Channel				X		
Top Soil		X	X		X	X

(2) Limitations. Some volatiles could continue to escape by diffusion and convection generated by atmospheric pressure changes (barometric pumping). Differential settlement due to consolidation of filled materials could cause cracking and leaking of the cap.

d. Underdrains. Leachate collection by underdrainage applies primarily to the upland disposal sites. It is also theoretically possible to stage disposal in a nearshore environment such that underdrains could be used to dewater the upper layer (unsaturated zone above tide line) of nearshore disposal sites. Underdrainage is a dewatering method which may be used either individually or in conjunction with improved surface drainage. In this procedure, collector pipes are placed in either a naturally occurring or artificially placed pervious layer prior to dredged material disposal. Upon disposal, free water in the dredged material migrates into the pervious underdrainage layer and is removed via the collector pipe system. Two mechanisms exist for dewatering and densification of fine-grained dredged material using pervious underdrainage layers:

(1) Gravity Underdrainage. This technique consists of providing free drainage at the base of the dredged material. Downward flow of water from the dredged material into the underdrainage layer takes place by gravity.

(2) Vacuum Assisted Underdrainage. This technique is similar to gravity underdrainage, but a partial vacuum is maintained in the underdrainage layer by vacuum pumping.

Design of an underdrainage layer for use with dredged material is somewhat different than design of a normal pervious filter. A continuous flow condition is usually not maintained in the underdrainage layer. Water essentially drips from the dredged material, and the static water level in the underdrainage layer is at the flowline of the collector pipe system. Fine-grained dredged material placed in confined disposal areas tends to exhibit individualized particle behavior, and it is necessary to choose a filter material that will resist both filter clogging and piping of the fine-grained dredged material through the filter.

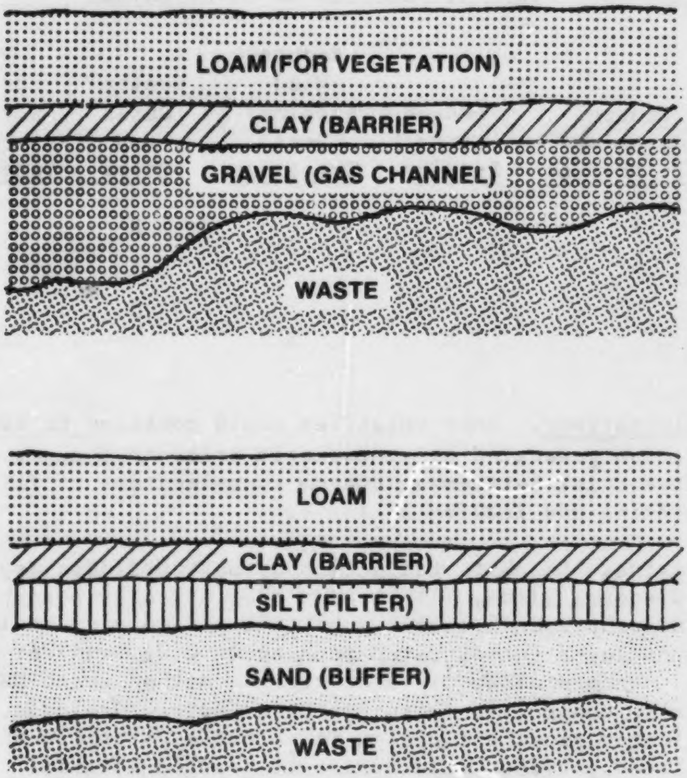


Figure 4-2: Examples of Surface Cover Systems

When placing underdrainage material over a liner for leachate collection, two choices are available: (1) creation of a drainage blanket and collector pipe system covering the entire site or (2) creation of a radial or herringbone-type underdrainage layer containing collector pipe. Which of these choices is most appropriate and cost effective is again a site-specific design problem.

(3) Limitations. All leachate collection underdrainage systems must be installed prior to disposal, but can be expected to last for long periods of time. If there is large drain spacing and a leak in the liner, leachate underdrainage may not collect all of the leachate. Drainage water (leachate) will persist for a long time at a slow rate of production.

e. Stabilization of Sediment. Sediment stabilization is useful for both bulk treatment and surface treatment. The stabilization of sediment in bulk can be done only for upland and nearshore sites and not for open-water sites. Surface stabilization may be used for all sites. Stabilization can be done through the use of chemical and physical stabilization techniques depending on the sediment composition. Physical techniques include the use of barriers to lower the velocity of the wind locally or to prevent wind from contacting the contaminated particulates. The introduction of soil surface barriers such as a gravel layer or soil blending are also effective physical stabilization techniques. Chemical stabilization includes the use of both mix up and spray on (surface applied) chemical additives. These materials prevent dust entrainment by causing the dust particles to adhere to one another, creating a smoother surface and a large mass that cannot be easily resuspended.

(1) Lime Treated Sediment. Lime addition to sediments has many beneficial effects. It is useful for both bulk and surface stabilization; it may be particularly useful for treating capping materials. Lime is mixed into clays for its effects as a flocculant. Lime will also promote some beneficial pozzolanic or cementing reaction in fine, cohesive soils which may continue to strengthen for many weeks. Lime addition will also raise the sediment pH and retard heavy metal release. Lime is used in combination with other additives such as fly ash. Although fly ash is not a cement in itself, when used in combination with lime or cement and water, fly ash will develop cementatious properties. The proportioning of soil, lime, and fly ash is dictated by economy and the desired properties in normal soil stabilization. Depending on the scarcity of cover soil or the availability of fly ash nearby, a normal mix for stabilization may include 20 percent fly ash, 5 percent lime, and 75 percent soil. However, mixtures containing 60 percent fly ash, 5 percent lime, and 35 percent sand may be just as effective.

(2) Dust Pallatives. The three general pallative methods commonly used are agronomic, surface penetration, and admix.

Agronomic methods consist of operations required to establish or preserve vegetative cover, mulch, shelter belts, and rough tillage. Vegetation cover is often considered to be the most satisfactory form of dust pallative based on esthetics, durability, cost, and maintenance. A well anchored mulch can also be used to stabilize soil. The mulch can consist of vegetative material, woven paper products, natural and synthetic netting, or a combination.

Surface penetration methods for sediment stabilization are accomplished by spraying the soil surface with a material and allowing this material to penetrate the soil under its own accord. Depending on the material, surface penetration applications may be accomplished with a liquid pressure distributor, by a gravity flow water distributor, or by hand spraying. There are a variety of spray on materials that can stabilize a sediment. These materials include asphalt, concrete, soil cement, soil asphalt, catalytically blown asphalt, and asphalt emulsions. Many of these materials can be sprayed directly on prepared surfaces in a liquid form which then solidifies to form a continuous membrane. Hydraulic asphalt concrete (HAC) is a hot mixture of asphalt cement and mineral aggregate that is resistant to the growth of plants and weather extremes and will resist slip and creep when applied to side slopes. The material should be compacted to less than 4 percent voids to obtain the lowest permeability possible. Soil asphalt is similar to soil cement; however, the soil used should be a low plasticity, gravelly soil with 10 to 25 percent silty fines. Catalytically blown asphalt is manufactured from asphalts with high softening points by blowing air through the molten asphalt in the presence of a catalyst such as phosphorus pentoxide or ferric chloride. The material can then be sprayed on a prepared surface regardless of cold or wet weather. As with soil asphalt, the membrane must be waterproofed with a hydrocarbon or bituminous seal. Asphalt emulsions can also be sprayed directly on prepared surfaces at temperatures above freezing. These membranes are less tough and have lower softening points than hot airblown asphalt. However, the toughness and dimensional stability can be increased by spraying onto supporting fabrics.

Admix methods of sediment stabilization result from blending a material with the sediment to produce a uniform mixture. This method requires more time, effort, and equipment than spray on techniques; however, it usually lasts longer. A variety of materials are suitable for use in the admix operations. The resulting soil cement is a low strength portland cement concrete with a permeability dependent upon the type of soil used. As expected, more granular soils produce more permeable soil cement; however, permeability coefficients as low as 1×10^{-6} cm/sec have resulted from the use of fine-grained soil. Coatings such as epoxy asphalt and epoxy coal tar have been used to decrease the permeability. Any nonorganic, well graded soil with less than 50 percent silt and clay can be used in soil cement. The soil should have a maximum size of 0.75 inch and a maximum clay content of 35 percent. The optimum moisture content is that which results in a maximum density (Shafer, 1984). Other admix soil stabilizers include chemical dispersants and swell reducers. Soluble salts such as sodium chloride, tetrasodium pyrophosphate, and sodium polyphosphate are added primarily to fine-grained soils with clay minerals to deflocculate the soils, increase their density, reduce permeability, and facilitate compaction. Additives are more effective with montmorillonite clay than with kaolinite or illite. Bentonite is a natural clay, composed primarily of montmorillonite, which is extremely fine grained and absorbent. Its high swelling properties make it suitable for mixing with soil and water to produce a low permeability cover layer. Any clay cover layer must be kept moist to avoid cracking. This is usually accomplished by covering with another soil layer in which vegetation is planted (JRB Assoc., 1982).

(3) Water Sprinkling. Sprinkling the surface with water will also limit windblown dust. The sprinkle rate must be closely matched with the variable evaporation rate for the most efficient operation and to minimize additional runoff.

(4) Limitations. Lime distribution from surface application does not ensure lime contact with the entire dewatered sediment. Also a disadvantage resulting from lime based stabilization is that the solid mass is porous. As such, consideration should be given to sealing the surface to prevent leaching of contained waste. Surface penetrant methods such as sprayed on asphalt have the disadvantages of high equipment and energy costs. Also, sprayed on asphalts have not been successful with some organic waste. Admixed methods for stabilization such as soil cement are incompatible with some wastes such as sodium salts of arsenate, borate, phosphate, iodate, and sulfide. Salts of magnesium, tin, zinc, copper, and lead along with organic matter are also incompatible. Cement is a porous solid and, therefore, contaminants can be expected to leach out over time. Water sprinkling can be effective in the short term but requires careful monitoring of application rates to avoid creating additional site runoff.

f. Biological Decontamination. Seeding a waste material with microorganisms to achieve degradation may be feasible if the waste has been determined to be biodegradable. Biodegradation has been used most widely for treatment of oily sludges and refinery wastes. Bacteria developed for biological seeding are capable of degrading benzenes, phenols, cresols, naphtolenes, gasolines, kerosenes, and cyanides (Ehrenfeld and Bass, 1983). The biodegradation process is relatively slow. Complete degradation of the waste could take several years and may never be complete if refractory compounds such as polynuclear aromatics are present. Biodegradation is an aerobic process for petroleum sludges and probably other organic wastes. Therefore, this technique is generally limited to those situations where the sediment is naturally aerated or where artificial aeration is feasible. Also, nutrient addition (nitrogen and phosphorus) and pH adjustment (lime addition) may be required. Thus, problems with respect to application and mixing of nutrients and lime into the sediment will exist. In addition, the biological decontamination treatment process is new and extensive field trials would have to be performed.

4.03 Treatment for Nearshore and Upland Disposal Sites.

4.03.01 Introduction. There are a variety of physical, chemical, and biological processes that have been developed for municipal and industrial water and waste treatment requirements. Many of these processes have potential in treating contaminated dredged material discharged at confined nearshore and upland disposal sites. However, few processes have actually been required for or applied to dredged material disposal. Among the processes widely applied in confined disposal are plain sedimentation for solids and sediment-bound contaminant removal, and chemical clarification and filtration for enhanced removal of particulate (suspended solids), sorbed metals, and organics. Use of activated carbon for removal of soluble organics has received some limited application to dredged material. Other processes not previously applied to dredged material include organics oxidation, dissolved solids removal methods (e.g., distillation), and volatiles stripping. This section describes and discusses each process in terms of demonstrated or potential removal efficiencies for solids, sediment-bound contaminants, soluble organics and metals, dissolved salts, and volatiles.

The water discharged from a disposal site will vary in quantity and quality over time. Site effluent will be produced in large quantities for hydraulically dredged sediments during the dredging process. This effluent will usually be of lower contaminant concentration than that found in the interstitial water and will almost always be of lower contaminant concentration than that of future water discharges from the site. Runoff water will be produced during site dewatering and periods of precipitation on the site. Runoff will be of concern primarily during the dewatering and prior to placement of a surface cap on the site. Runoff water may be of higher contaminant concentration than the original site effluent. Leachate water is produced as water moves through the sediments and out the sides and bottom of a disposal site. This water is produced in the smallest quantities but may contain relatively high contaminant concentrations and may persist for a long period of time. Leachate treatment usually requires collection via drains placed under the site (underdrains). This section applies mainly to treatment of site effluent; long-term site runoff and leachate are discussed in section 4.04.

Table 4-3 lists water treatment methods and indicates which of these have been applied to dredged material disposal. These treatment processes can be grouped into various levels of treatment, depending upon a particular phase or class of contaminant being removed. Four levels of treatment were identified and are defined as follows:

- Level I is the removal of solids and particulate-bound contaminants.
- Level II is additional treatment to remove soluble metals.
- Level III is further processing to remove soluble organics.
- Level IV is the purification of water by dissolved solids removal.

The relationships between levels of treatment are illustrated in plate 3. A comparison of the relative efficiencies of the treatment levels is given in table 4-4. Increasing levels of treatment result in increasing percentages of contaminant removal. The qualitative ranges of soluble concentrations remaining after each treatment level and percent removals are based on actual monitoring of disposal sites for Levels I and II (where applicable) and on best available water treatment technology for Levels III and IV. It should be noted that the estimates made for soluble organics and soluble metals removals past Level I are mean values and represent a grouping of contaminants with large ranges of solubility and treatability. The data in table 4-4 should be viewed as preliminary for planning purposes only, and as such, are presented to illustrate potential levels of removals. Actual removal efficiency data on Commencement Bay sediments would have to be obtained through site-specific testing, evaluations, and demonstrations.

TABLE 4-3

LISTING OF WATER TREATMENT PROCESSES

Treatment Process	Proven Method	Proven Not Demonstrated	Applied to Dredged Material	Not Applied to Dredged Material
Suspended Solids				
Plain Sedimentation	X		X	
Chemical Clarification	X		X	
Filtration	X		X	
Soluble Metals				
Precipitation	X		X[a]	
Soluble Organics				
Adsorption	X		X	
Ozonation	X			X
Dissolved Solids				
Distillation	X			X
Reverse Osmosis	X	X		X
Electrodialysis	X			X
Ion Exchange	X			X
Volatiles				
Stripping	X			X
Leachate[b]				
Biological	X			X
Physical/Chemical	X[b]			X

[a] Limited success on pilot scale.

[b] Potential for use of existing municipal or industrial process for treatment offsite.

TABLE 4-4

CONTAMINANT REMOVAL EFFICIENCY OF WATER TREATMENT LEVELS[1]

Level	Class of Contaminant	Percent Removal	Water Concentration Remaining
I	Solids	99.9+	mg/l range
	Metals	80 to 99+	ppb to ppm range[2]
	Organics	50 to 90+	ppb to ppm range[2]
II	Metals	99+	ppb range[2]
	Organics	50 to 90	ppb to ppm range[2]
III	Metals	99+	ppb range[3]
	Organics	95+	ppb range[3]
IV	Metals	99+	highest quality attainable[3]
	Organics	99+	highest quality attainable[3]

1/Assumes influent strength defined by dredged sediments that are not classifiable as "extremely hazardous waste" under RCRA (i.e., "low saturation" influents, see last paragraph of section 6.05).

2/Concentrations based on Hoeppel, et al., 1978, and Palermo, in preparation.

3/Concentrations based on capability of "best available treatment" technology.

4.03.02 Plain Sedimentation.

a. Overview. Many of the contaminants present in the flow from a hydraulic dredging operation will be removed during the plain sedimentation occurring within a confined disposal area. Confined disposal areas are used to retain dredged material solids while allowing the carrier water to be released from the disposal area. The effluent may contain levels of both dissolved and particulate-associated contaminants.

Release of supernatant waters from confined disposal sites occurs after a retention time of up to several days. Actual withdrawal of the supernatant is governed by the hydraulic characteristics of the ponded area and discharge weir discussed in chapter 3 above. Procedures have been developed to predict concentrations of suspended solids in disposal area effluents, taking into account settling behavior of the sediment in question. All solids cannot be retained during the disposal process, and associated contaminants are transported with particulates in the effluent to the receiving water. Therefore, predictions of suspended solids concentrations expected in the effluent can often be used to estimate contaminant losses and determine need for further solids removal treatment. Similar testing can be done to determine treatment requirements for soluble contaminants (Palermo, 1984).

b. Contaminant Removal by Plain Sedimentation. Properly designed and operated confined disposal areas can be extremely efficient in retaining suspended solids and associated contaminants. This is especially true if the dredging is conducted in a saltwater environment as is the case for Commencement Bay. Palermo (in preparation) found that retention efficiency for suspended solids in three saltwater disposal areas was above 99.9 percent (inflow solids concentrations on the order of 100 g/l and effluent suspended solids concentrations on the order of tens of mg/l). Similar high retention of the total concentration of metals was observed, varying from 84.5 to 99.9 percent. These data are in agreement with Hoeppel, et al. (1978), and other investigators. Hoeppel, et al. (1978), described similar retention for organics such as PCB and DDT which remain closely associated with particles. Typical concentrations of various contaminants remaining in the effluent following plain sedimentation are available in Hoeppel, et al. (1978), and Palermo (in preparation), and are summarized in table 4-4.

4.03.03 Chemical Clarification.

a. Applicability. Chemical clarification is an effective treatment method to remove turbidity, suspended solids, and adsorbed contaminants from the effluent of a fine-grained dredged material containment area. The process is used following plain sedimentation to reduce the required chemical dosage and, therefore, the cost of treatment and to produce a higher quality effluent than could be produced in a one-stage settling process (Schroeder, 1983). However, chemical clarification is an ineffective method for removing soluble contaminants.

The chemical clarification process can be adapted and simplified to perform within the constraints of a normal disposal operation (Schroeder, 1983). In this process, a liquid polymeric flocculant is fed into the effluent from the primary containment area at the weir structure. The weir structure and discharge culvert are used to provide the required mixing without mechanical equipment. A small secondary containment area is used for settling and storage of the treated material, eliminating the need for a clarifier and sludge handling equipment. However, a mud pump may be used to pump the settled, treated material back into the primary containment area and to reduce the required size of the secondary containment area. A sketch of the treatment process is shown in figure 4-3.

Liquid polymeric flocculants are much simpler and less expensive to use than inorganic coagulants such as ferric chloride and alum (Wang and Chen, 1977). The treatment system described above is also less expensive than a conventional system requiring a flash mixer, flocculation basin, clarifier, and sludge handling equipment (Schroeder, 1983; and Jones, et al., 1978).

b. Limitations. Chemical clarification must follow plain sedimentation and will not appreciably remove soluble and volatile contaminants.

c. Removal Efficiency. Chemical clarification, as applied here, can remove up to 95 percent of the suspended solids and achieve an effluent quality of 25 mg/l suspended solids (Schroeder, 1983). Adsorbed contaminants are reduced in proportion to suspended solids removal.

4.03.04 Filtration. Filtration is a treatment process used to provide additional removal of suspended solids and sediment-bound contaminants following plain sedimentation and chemical clarification. The process has been adapted to dredging operations through the use of pervious dikes and sandfill weirs (Krizek, et al., 1976).

a. Pervious Dikes. Pervious dikes should use coarse-grained deep beds that have low clarification efficiency per unit depth but maintain high permeability throughout the filter life. The dike must not face clog or lose its ability to achieve the required clarification. Example pervious dikes are shown in figure 4-4. Typically, the dikes are 6 to 10 feet high and the filter medium is coarse sand (Krizek, et al., 1976; and Culp, et al., 1978).

b. Sandfill Weirs. Sandfill weirs consist of several cylindrical or rectangular cells that contain the filter medium and provide filtration in a vertical gravity flow. Sandfill weirs are much more flexible than filter dikes allowing easier replacement and maintenance. Example sandfill weirs are shown in figure 4-5. The depth of the filter medium is generally kept as deep as possible to provide better solids retention. The filter medium is generally sand with a particle size of about 1 milimeter (mm) (Krizek, et al., 1976).

c. Limitations.

(1) Pervious Dikes. If the system malfunctions, corrective measures, if at all possible, are extremely expensive. The water to be treated should have less than 1.0 g/l suspended solids. The filter medium should be carefully selected to remove the suspended solids deep inside the fiter and not at the face to prevent clogging and loss of efficiency (Krizek, et al., 1976).

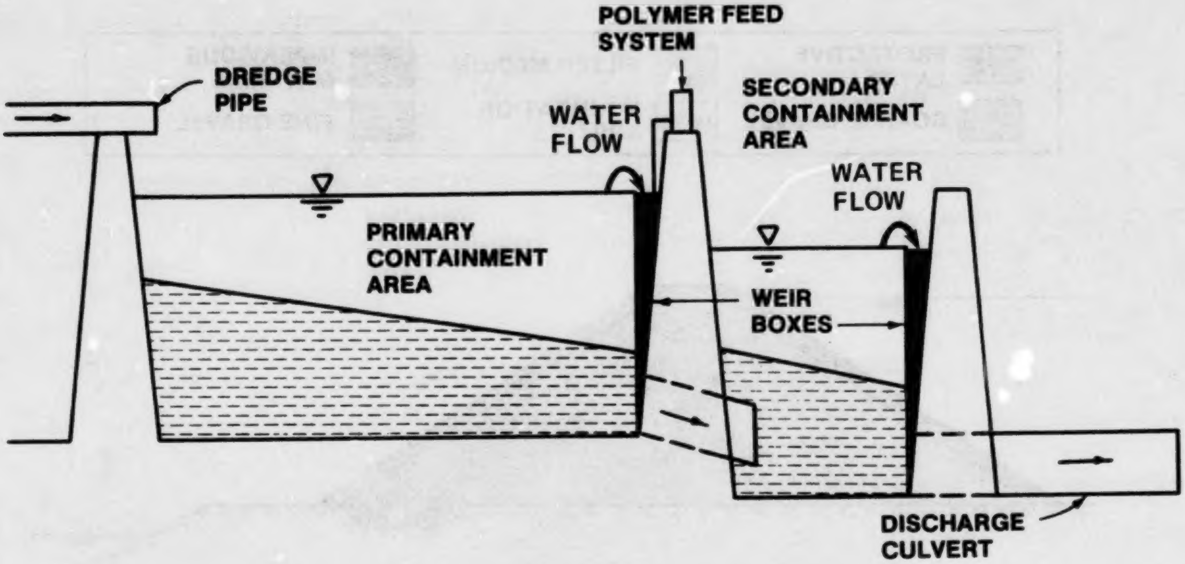
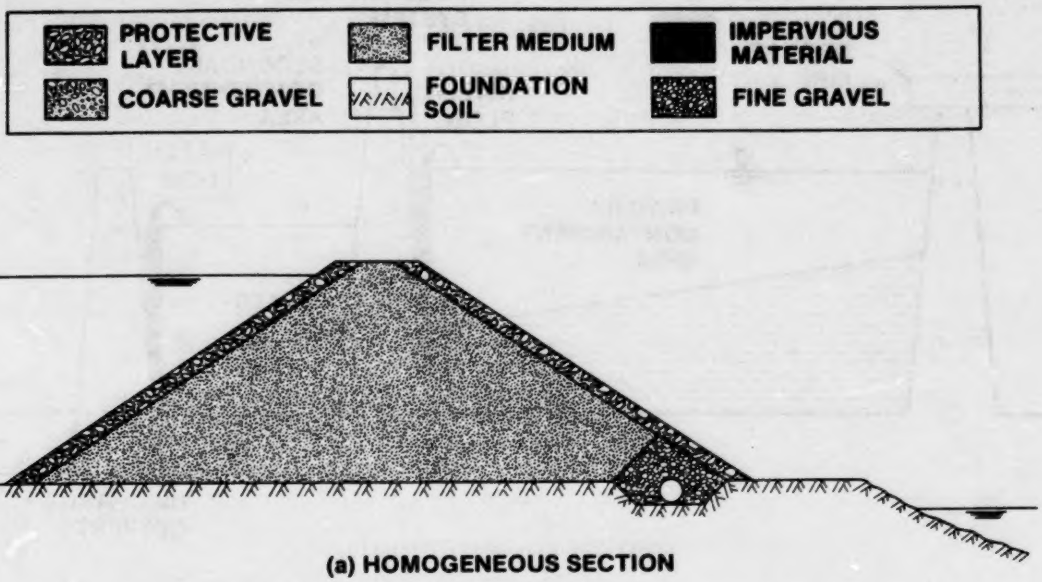
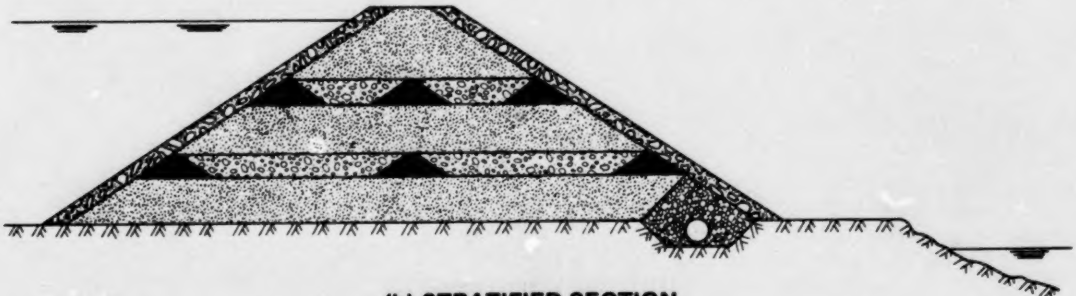


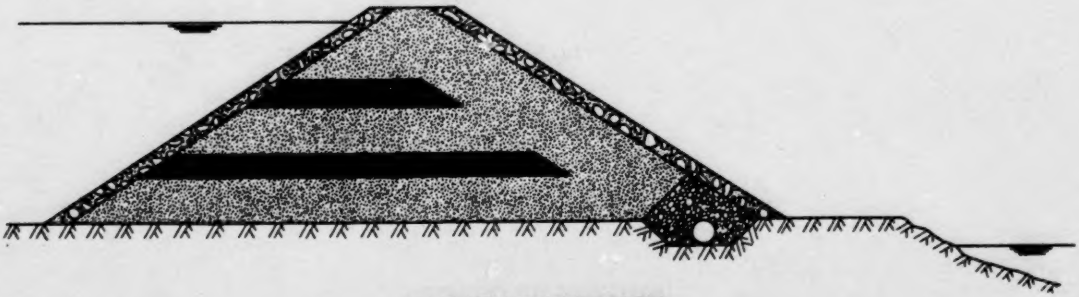
Figure 4-3: Schematic of Chemical Clarification Facility



(a) HOMOGENEOUS SECTION



(b) STRATIFIED SECTION



(c) BAFFLED SECTION

Figure 4-4: Pervious Dikes

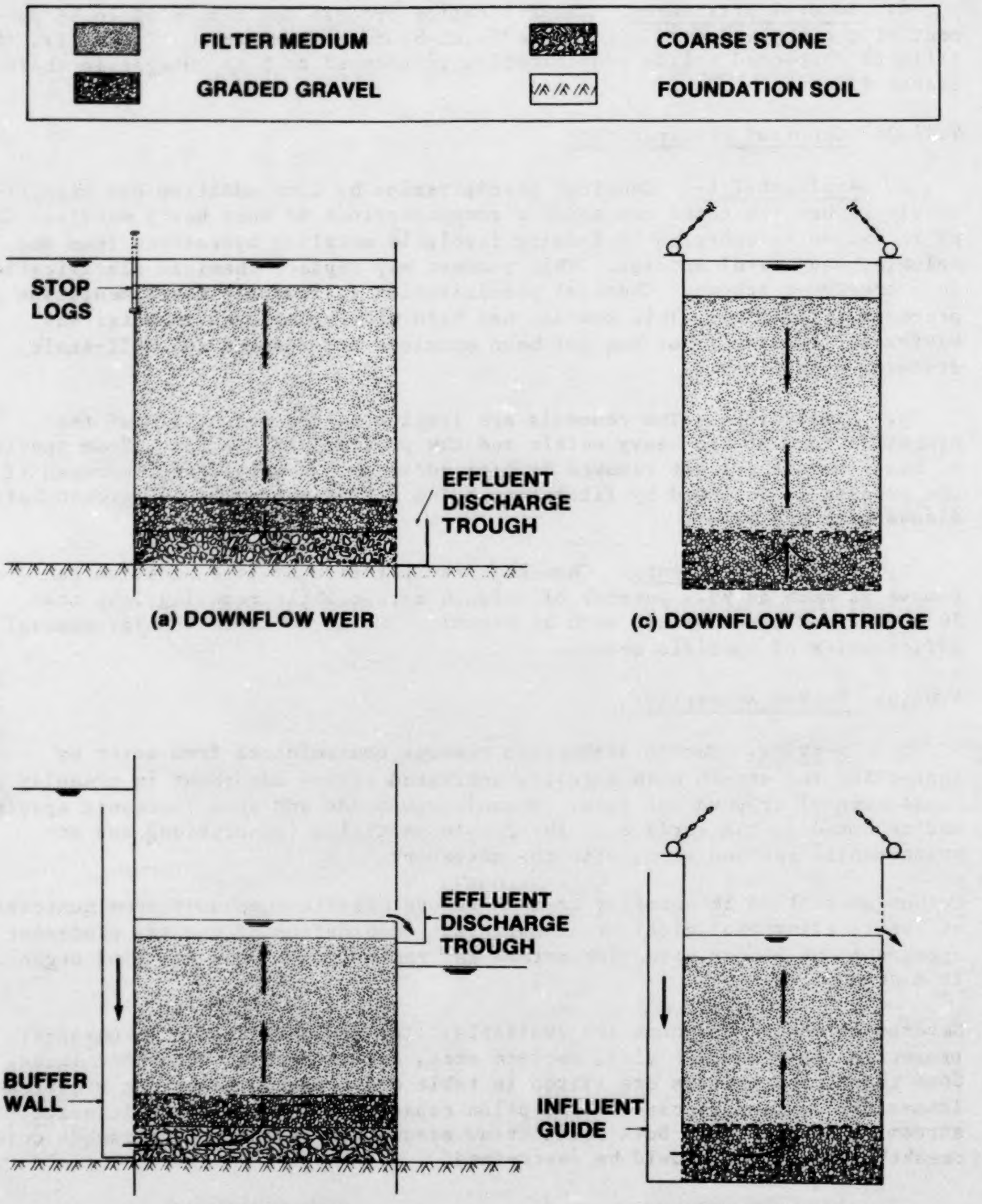


Figure 4-5: Sandfill Weirs

(2) Sandfill Weirs. Sandfill weirs require excessive maintenance if the influent contains more than 1 g/l suspended solids (Krizek, et al., 1976).

d. Removal Efficiency. The filtration process can remove 60 to 98 percent of the suspended solids and sediment-bound contaminants. Typically, the effluent suspended solids concentration is reduced to 5 to 10 mg/l in these coarse filters.

4.03.05 Chemical Precipitation.

a. Applicability. Chemical precipitation by lime addition can significantly reduce the total and soluble concentrations of many heavy metals. The pH is raised to above pH 11 forming insoluble metallic hydroxides from the soluble heavy metal species. This process may replace chemical clarification in a treatment scheme. Chemical precipitation follows plain sedimentation and precedes filtration. This process has been widely employed in water and wastewater treatment but has not been examined and adapted for full-scale dredging operations.

b. Limitations. The removals are limited by the solubility of the hydroxide form of the heavy metals and the precipitate removal. Some species of heavy metals are not removed by lime addition. Removals are improved if the process is followed by filtration. The effluent pH must be lowered before discharging the water.

c. Removal Efficiency. Chemical precipitation by lime addition can remove as much as 99.9 percent of certain metals while removing less than 10 percent of other metals such as arsenic. Refer to table 4-5 for removal efficiencies of specific metals.

4.03.06 Carbon Adsorption.

a. Overview. Carbon adsorption removes contaminants from water by contacting the stream with a solid, activated carbon adsorbent in granular (most common) or powdered form. Organic compounds and some inorganic species become bound to the surface of the carbon particles (adsorption) and are subsequently removed along with the adsorbent.

Carbon adsorption is normally used to remove organic compounds from municipal effluents after biological treatment. The combination of the two processes appears to be a cost effective method for removal of a wide range of organics from aqueous wastes.

Several commercial carbons are available. The products differ in physical properties such as pore size, surface area, and adsorption characteristics. Some commercial carbons are listed in table 4-6. Carbon selection requires laboratory testing of carbon adsorption capacities for the specific waste stream to be treated. Both equilibrium adsorption isotherms and carbon column breakthrough curves should be determined.

TABLE 4-5

REMOVAL OF HEAVY METALS BY LIME COAGULATION AND RECARBONATION

Metal	Reference	Concentration Before Treatment mg/l	Concentration After Treatment mg/l	Final pH	% Removal
Antimony[a]	5	—	—	11	90
Arsenic[a]	5	—	—	11	<10
	18	23	23	9.5	0
Barium[a]	5		~1.3 (sol)[b]	11	
Bismuth[a]	5		.0002 (sol)	11	
Cadmium	9	Trace		11	~50
	10	0.0137	0.00075	>11	94.5
	10	0.056	0.050	>11	11
Chromium (+6)	10	7,400	2.7	8.7	99.9$^+$
Chromium (+3)	11	15	0.4	9.5	97
	18	15,700	0.79	8.7	99.9$^+$
Copper	11	7	1	8	86
	12	7	.05	9.5	93
	12	302	Trace	9.1	99$^+$
	13	15	0.6	9.5	97
	18		<.001 (sol)	11	90$^+$
Gold[a]	5	13	2.4	9.1	82
Iron	13	17	0.1	10.8	99$^+$
	14	2.0	1.2[c]	10.5	40
	14	—	<.001 (sol)[b]	11	90$^+$
Lead[a]	5	15	0.5	9.5	97
	18	2.3	<0.1	10.8	96
Manganese	14	2.0	1.1[c]	10.5	45
	14	21.0	0.05	9.5	95
	15		Oxide soluble		<10
Mercury[a]	5	Trace	—	8.2	~10
Molybdenum	9	11	9	9.5	18
	18	160	0.08	8.7	99.9$^+$
Nickel	11	5	0.5	8.0	90
	12	5	0.5	9.5	90
	12	100	1.5	10.0	99
	16	16	1.4	9.5	91
	18	0.0123	0.0103	>11	16.2
Selenium	10	0.0546	0.0164	>11	97
Silver	10		(<0.001?)	11	(?90$^+$)
Tellurium[a,d]	5		(<0.001?)	11	(?90$^+$)
Titanium[a,d]	5		?		?
Uranium[e]	5		.007 (sol)	11	90$^+$
Zinc	5	17	0.3	9.5	98
	18				

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[a] The potential removal of these metals were estimated from solubility data.

[b] Barium and lead reductions and solubilities are based upon the carbonate.

[c] These data were from experiments using iron and manganese in the organic form.

[d] Titanium and tellurium solubility and stability data made the potential reduction estimates unsure.

[e] Uranium forms complexes with carbonate ion. Quantitative data were unavailable to allow determination of this effect.

Reference: Culp and Culp, 1974

TABLE 4-6
PROPERTIES OF SEVERAL COMMERCIALLY AVAILABLE CARBONS[a]

PHYSICAL PROPERTIES	ICI AMERICA HYDRODARCO 3000	CALGON FILTRASORB 300 (8x30)	WESTVACO NUCHAR WV-L (8x30)	WITCO 517 (12x30)
Surface area, m^2/gm (BET)	600-650	950-1050	1000	1050
Apparent density, gm/cc	0.43	0.48	0.48	0.48
Density, backwashed and drained, lb/cu ft	22	26	26	30
Real density, gm/cc	2.0	2.1	2.1	2.1
Particle density, gm/cc	1.4–1.5	1.3–1.4	1.4	0.92
Effective size, mm	0.8–0.9	0.8–0.9	0.85–1.05	0.89
Uniformity coefficient	1.7	1.9 or less	1.8 or less	1.44
Pore volume, cc/gm	0.95	0.85	0.85	0.60
Mean particle diameter, mm	1.6	1.5–1.7	1.5–1.7	1.2
SPECIFICATIONS				
Sieve size (U.S. std. series)				
Larger than No. 8 (max. %)	8	8	8	c
Larger than No. 12 (max. %)	c	c	c	5
Smaller than No. 30 (max. %)	5	5	5	5
Smaller than No. 40 (max. %)	c	c	c	c
Iodine No.	650	900	950	1000
Abrasion No., minimum	b	70	70	85
Ash (%)	b	8	7.5	0.5
Moisture as packed (max. %)	b	2	2	1

[a] Other sizes of carbon are available on request from the manufacturers.
[b] No available data from the manufacturer.
[c] Not applicable to this size carbon.

Source: ADL, 1976

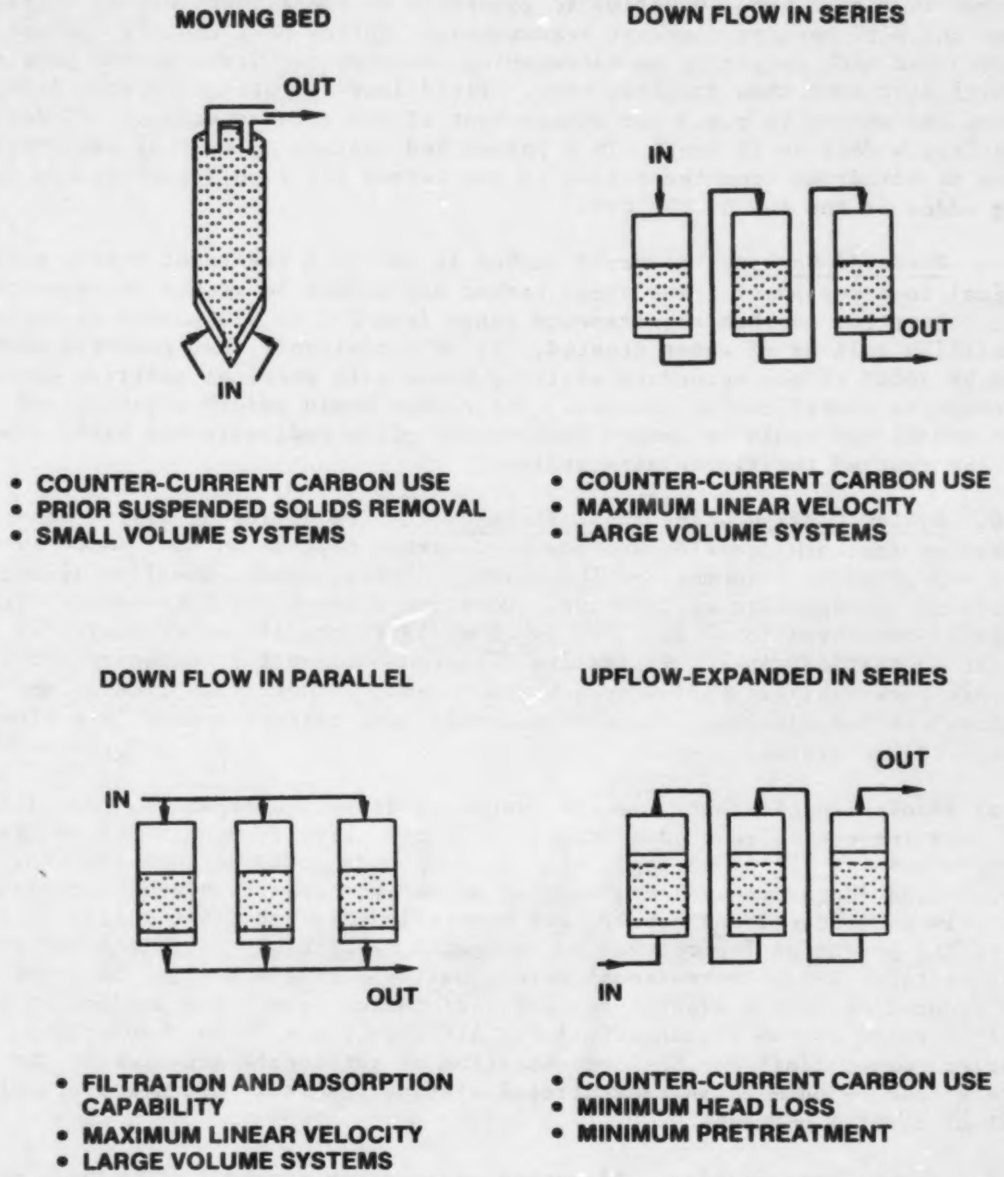
b. Carbon Columns. Carbon columns can be used in either upflow or downflow configuration and can be arranged in either series or parallel operation as shown in figure 4-6. Downflow is generally an inefficient use of activated carbon and will require frequent backwashing. Upflow beds usually operate in expanded bed mode requiring no backwashing, but may require pressure pumping and will cost more than downflow beds. Field loading rates vary from 2 to 10 gallons per minute (g.p.m.) per square foot of bed cross section. Bed depths range from 4 feet to 20 feet. In a pulsed bed system, a layer of exhausted carbon is withdrawn from the bottom of the carbon bed with a regenerated layer being added to the top of the bed.

c. Powdered Carbon. Powdered carbon is fed to a treatment system using chemical feed equipment. The spent carbon may either be wasted or recovered and regenerated. Carbon requirements range from 250 to 350 pounds of carbon per million gallons of water treated. It is conceivable that powdered carbon could be added to the secondary settling basin with chemical addition during the chemical clarification process. The carbon would adsorb organics and trace metals and could be pumped back to the plain sedimentation basin along with the rest of the flocculated solids.

d. System Configuration and Efficiencies. The choice of system configuration for both granular and powdered carbon depends on many factors. Table 4-7 presents a summary of the primary determinants. The flow direction depends on the specific application. Downflow systems can accommodate higher suspended concentrations (i.e., 65 to 70 mg/l) if the liquid viscosity is similar to that of water. Solids are filtered out and the column requires periodic backwashing. Upflow systems can handle more viscous liquids and require less bed washing. The most commonly used contact method is a flow through column system.

Carbon adsorption technology is applicable to dissolved organics, generally. Many organics can be reduced to the 1 to 10 ug/l level. Results of an EPA study showed that 51 of 60 toxic organic compounds could be removed (EPA, 1980). Some inorganic species, such as antimony, arsenic, bismuth, chromium, tin, silver, mercury, and cobalt, are partially adsorbed (EPA, 1982). A listing of the potential for removal of inorganic material by activated carbon is given in table 4-8. Conventional water quality parameters (BOD, COD, TOC) are also reduced by carbon adsorption; the performance level is dependent on the specific waste stream characteristics. Although there is no theoretical, technical upper limit for the concentration of adsorbable organics in the waste stream, economics in conventional systems generally dictate a practical limit of about 1 percent.

e. Carbon Regeneration. If carbon usage rates exceed 1,000 pounds per day, regeneration of carbon is generally feasible. Regeneration of spent carbon may be accomplished by a variety of means, the most common involving thermal destruction of the adsorbed organics in a multiple hearth furnace. About 5 to 10 percent of the carbon is lost in this regeneration process (and most other processes) due to the creation of fines from the mechanical handling of the carbon. Other regeneration processes include thermal treatment with steam, extraction of adsorbed organics with solvents (including acids, bases, and super critical fluids), and biological degradation of the adsorbed material.



MOVING BED

- COUNTER-CURRENT CARBON USE
- PRIOR SUSPENDED SOLIDS REMOVAL
- SMALL VOLUME SYSTEMS

DOWN FLOW IN SERIES

- COUNTER-CURRENT CARBON USE
- MAXIMUM LINEAR VELOCITY
- LARGE VOLUME SYSTEMS

DOWN FLOW IN PARALLEL

- FILTRATION AND ADSORPTION CAPABILITY
- MAXIMUM LINEAR VELOCITY
- LARGE VOLUME SYSTEMS

UPFLOW-EXPANDED IN SERIES

- COUNTER-CURRENT CARBON USE
- MINIMUM HEAD LOSS
- MINIMUM PRETREATMENT

Figure 4-6: Granular Activated Carbon System Configuration

TABLE 4-7

CONTACTING SYSTEMS

Method	Application Conditions	Comments
Single or parallel adsorbers	Pollutant breakthrough curve is steep. Carbon recharge interval is long. Volume flow is high. Influent is viscous.	Typical flows are 1 to 4 gpm/ft^2. Parallel system is usually selected if pressure drop problems are expected for the system. Moderate adsorbent expense.
Adsorbers in series	Pollutant breakthrough curve is gradual. Uninterrupted operation is necessary. Relatively low effluent concentration is required. Carbon recharge interval is short.	Typical flows are 3 to 7 gpm/ft^2. High adsorbent expense.
Expanded upflow adsorber(s)	For high flows and high suspended solids concentrations.	Typical flows are 5 to 9 gpm/ft^2. Suspended solids are passed through the column and not separated.
Moving Bed	For systems requiring efficient use of carbon (i.e., carbon adsorption capacity is exhausted before removal from column).	Influent must contain less than 10 mg/l TSS, and not biologically active. Either parameter will cause a pressure drop in the system and necessitate removal of carbon prior exhaustion of its absorption capacity.
Powdered carbon with subsequent clarifier and/or filter	Carbon usage higher than for series of fixed-bed adsorbers. Influent concentration of pollutants should be relatively constant to avoid frequent sampling and adjustment of carbon dosage.	No restrictions on suspended solids or oil and grease in influent. Capital equipment costs relatively low. Simple to operate.
Powdered activated carbon with activated sludge	For activated sludge systems receiving toxic or shock organic loadings.	Protects the biological system from toxic organics and shock loadings. Generally improves effluent quality.

Source: ADL, 1976.

Table 4-8

POTENTIAL FOR REMOVAL OF INORGANIC MATERIAL BY ACTIVATED CARBON

Constituents	Potential for Removal by Carbon
Metals of high sorption potential:	
Antimony	Highly sorbable in some solutions
Arsenic	Good in higher oxidation states
Bismuth	Very good
Chromium	Good, easily reduced
Tin	Proven very high
Metals of good sorption potential:	
Silver	Reduced on carbon surface
Mercury	CH_3HgCl sorbs easily, metal filtered out
Cobalt	Trace quantities readily sorbed possibly as complex ions
Zirconium	Good at low pH
Elements of fair-to-good sorption potential:	
Lead	Good
Nickel	Fair
Titanium	Good
Vanadium	Variable
Iron	FE^{3+} good, FE^{2+} poor, but may oxidize
Elements of low or unknown sorption potential:	
Copper	Slight, possible good if complexed
Cadmium	Slight
Zinc	Slight
Beryllium	Unknown
Barium	Very low
Selenium	Slight
Molybdenum	Slight at pH 6-8, good as complex ion
Manganese	Not likely, except as MnO_4
Tungsten	Slight
Miscellaneous inorganic water constituents:	
Phosphorus	
P, free element	Not likely to exist in reduced form in water
PO_4^{3-} phosphate	Not sorbed but carbon may induce precipitation $Ca_3(PO_4)_2$
Free halogens:	
F_2 fluorine	Will not exist in water
Cl_2 chlorine	Sorbed well and reduced
Br_2 bromine	Sorbed strongly and reduced
I_2 iodine	Sorbed very strongly, stable
Halides	
F^- flouride	May sorb under special conditions
Cl^-, BR^-, I^-	Not appreciably sorbed

f. Limitations. Carbon adsorption system performance is sensitive to the composition of the influent and flow variations. Because a system design based on good data can perform poorly if influent conditions change, systems are generally oversized. For fixed bed, granular carbon systems, special attention must be given to the materials of construction (to prevent corrosion and mechanical failure) and to the materials handling equipment (pipes, pumps, valves, controls) for the transfer of carbon to and from various tanks and/or regeneration units.

Care must be taken to ensure that the adsorption capacity of the carbon is not reduced either by chemicals, resins, or fine precipitates in the influent or by the continued presence of similar chemicals in the residual water (after draining) if the carbon is thermally regenerated. In the latter case, any material (e.g., inorganic salts, some resins) that are not volatilized or combusted during regeneration will remain in the pores of the carbon resulting in an irreversible loss of adsorption capacity.

In all cases, it is prudent to consider the possibility of biological activity in the carbon system. Such activity can help (via pollutant biodegradation) or hinder (via clogging and/or odor generation) the process. Suspended solids and oil/grease can interfere with carbon adsorption treatment. Influent concentrations of these pollutants should not exceed 50 ppm and 10 ppm, respectively (ADL, 1976).

Treatment of highly saline waters has the potential of resulting in insoluble salt formation during carbon regeneration. Rinsing spent carbon with freshwater prior to regeneration should prevent this potential problem. Site-specific design studies will indicate if carbon regeneration is appropriate and if freshwater washing is needed.

4.03.07 Ozonation.

a. Overview. In ozonation, contact with ozone, a powerful oxidizing agent, breaks down many refractory organic compounds not treatable with biological treatment techniques. Ozone, produced in a separate generator, is introduced to a contactor where it mixes with the wastes and reacts with oxidizable species present.

Ozone dose rate is usually expressed as either ppm ozone or pounds of ozone per pound of stream contaminants treated. Typical dose rates are 10 to 40 ppm for the former and 1.5 to 3.0 pounds per pound of contaminant removed for the latter (ADL, 1976). Retention time ranges from 10 minutes to 1 hour in several stages.

Typically, the very high ozone to waste ratios are encountered in potable water facilities where the influent contaminant concentrations are in the ppb range and the effluent concentrations are nondetectable.

b. Effectiveness. Ozonation is applicable only to dilute wastes, typically containing less than 1 percent oxidizable materials. The destructive power to refractory compounds may be enhanced by combining ozonation with ultraviolet radiation (Prengle, et al., 1975). Ozonation is effective with:

- chlorinated hydrocarbons,
- alcohols,
- chlorinated aromatics,
- pesticides, and
- cyanides.

Large contactors are required because reaction rates are mass transfer limited; ozone has only limited solubility in water. Contactor depth is typically on the order of 5 m (16 feet) to ensure adequate mixing and reaction time. Ultraviolet lamps, if used, are operated within the contactor vessel.

c. Limitations. Ozone is corrosive, requiring special construction materials. Suitable materials include:

- stainless steel,
- unplasticized PVC,
- aluminum,
- teflon (registered trademark), and
- chromium-plated brass or bronze.

Ozone is acutely toxic; personnel safety is therefore a major concern. Modern systems are completely automated. An ozone monitor measures ozone levels in the gaseous effluent and reduces the ozonator voltage or frequency if gaseous levels exceed a pre-set limit (usually 0.05 ppm). An ambient air monitor sounds an alarm and shuts off the ozonator in the event of leaks of ozonized air. An off-gas ozone destruction unit is also generally used in modern systems.

4.03.08 Dissolved Solids Removal Systems.

a. Overview. There are a number of processes that can be applied to the treatment of brackish and highly saline waters. These processes include, but are not limited to, distillation or evaporation, electrodialysis, ion exchange, and reverse osmosis. In the case of nearshore and upland treatment, these processes would only be used to achieve the highest quality of water. Because of the high initial investment and intensive energy and operation requirements, dissolved solids removal is rarely used except in production of potable drinking water or high quality water for industrial operations. There have been no known applications of dissolved solids removal associated with any dredging operation.

b. Distillation. Distillation or evaporation of saline water to produce freshwater goes back to antiquity. In distillation or evaporation processes, pore water vapor is created by heating saline water. The vapor is separated from the saline water and is condensed to form pure water.

There are three principal types of distillation processes currently being used on new construction. These are:

- long-tube vertical (LTV),
- multistage flash (MSF), and
- vapor compression (VC).

In LTV distillation, the water to be vaporized flows by gravity down the inside of a long vertical tube, while steam or hot vapor supplies heat on the outside.

In MSF distillation, the water is heated under pressure in tubes and then allowed to expand suddenly or "flash" into a chamber. As some of the water evaporates or flashes, the remaining water cools slightly and then flows into another chamber at lower pressure where it flashes again. The flashed vapor condenses on the outside of the tubes in each chamber through which cooler water is flowing and picking up heat. The condensed pure water then drips into collecting pans and is pumped to service.

In VC distillation, pure water vapor, which has been evaporated at a tube surface or in a flash chamber, is mechanically compressed (usually by a centrifugal or axial flow gas compressor) to raise its temperature and pressure for use in vaporizing more water. VC cycles must utilize mechanical or electrical energy or work rather than heat as the primary energy input for distillation.

These distillation processes can be combined and there are many individual modifications, depending upon the amount, type, and cost of available steam, power, water, and other basic factors.

c. Electrodialysis. Today, electrodialysis (ED) is a widely used process for the treatment of brackish or highly mineralized waters. In ED, salts and minerals are removed from a stream of saline water through special plastic membranes by the action of a direct electrical current. The salts and minerals pass through the membranes in the form of positively and negatively charged ions. The water from which these ions have been removed flows between the membranes and is collected as a partially demineralized product via manifolds cut through the membranes. The salts and minerals removed from the product stream pass through the membranes into another stream of water which continuously washes the other side of each membrane and emerges through manifolds as a more concentrated waste stream. ED can operate at low pressures (approximately 50 psi).

d. Reverse Osmosis. Over the past decade, very thin membranes have been synthesized from cellulose acetate, and more recently from nylon, that pass relatively pure water and retain relatively salty water when a saline water is forced against them by high pressure. This filtration-like process is generally referred to as reverse osmosis (RO).

RO units of different types and sizes have been built and operated for various periods since the early 1960's. Most units have ranged from laboratory scale to a few thousand gallons per day. Several units in the 50,000- to 100,000-gpd range have been assembled, but significant field data or field experience are not yet available on these larger units.

e. Effectiveness.

(1) Distillation. Distillation can result in 99+ percent removal of contaminants. Distillation plants having capacities up to several million gallons per day are in operation at a number of locations throughout the world and have proven their reliability.

(2) Electrodialysis. ED plants having capacities up to about 1 million gallons per day are in operation at a number of locations throughout the world and have proven their reliability to produce freshwater for utility use. Removal of inorganics is very high (90+ percent).

(3) Reverse Osmosis. RO is capable of removing greater than 90 percent of total dissolved solids (TDS) from wastewater streams containing up to 50,000 mg/l TDS. Organics with molecular weight in excess of 300 to 500, such as pesticides, can be removed at efficiencies exceeding 90 percent. Operation is sensitive to wastewater pH, total suspended solids levels, and TDS levels.

f. Limitations.

(1) Distillation. Distillation plants require substantial amounts of thermal energy or electrical power. Accordingly, the cost and availability of energy are important factors in both the design and economic feasibility of distillation plants.

Close attention to water chemistry is essential to maintain the vital heat transfer surfaces of distillation equipment at peak efficiency. The chemistry and biochemistry of seawater vary substantially at different locations and expert advice should be sought on the optimum chemical and mechanical treatments and operating conditions to avoid excessive corrosion, hard scale formation, or marine fouling.

(2) Electrodialysis. ED plants require clear waters free from iron, manganese, turbidity, and organic matter for optimum operations. Accordingly, pretreatment of water by conventional means is always required prior to ED

plants operating on surface water. ED plants will generally require from 10 to 30 percent of the feed water to carry off the concentrated salts and minerals removed.

(3) Reverse Osmosis. Certain problems of the RO field are under intensive study and development. Pretreatment is often required to handle the following condition:

- Leachate Variability. Rapidly changing leachate properties such as pH, temperature, and suspended solids concentration can limit membrane life requiring frequent replacement. Leachate equalization prior to the RO treatment should be considered if highly variable conditions exist.

- Leachate pH. Because membrane operation is limited to certain pH ranges, pH adjustment should precede RO operation if necessary.

- Biological Organisms. Living organisms in leachate can form films on RO membranes which reduces permeability. Such organisms should be destroyed by chlorination or ozonation prior to RO treatment.

- Total Suspended Solids (TSS). TSS can plug RO modules, particularly the hollow fiber type. Suspended solids should be minimized to particle sizes less than about 10 microns prior to introduction in most RO modules.

4.03.09 Stripping.

a. Overview. Stripping removes volatile contaminants from an aqueous waste stream by passing air or steam through the wastes. With air, the volatile, dissolved gases are transferred to the air streams for treatment such as carbon adsorption or thermal oxidation. With steam the process is, in essence, a steam distillation of the waste with the volatile contaminants ending up in the distillate for treatment. Typical system configurations are shown in figures 4-7 and 4-8.

b. Effectiveness. Both versions of stripping are capable of high removal efficiencies. Air stripping of ammonia from wastewaters has exceeded 90 percent for influent ammonia concentrations of less than 100 ppm (ADL, 1976), and 99+ percent has been achieved for removal of trichloroethylene from ground water. Steam stripping can be applied to:

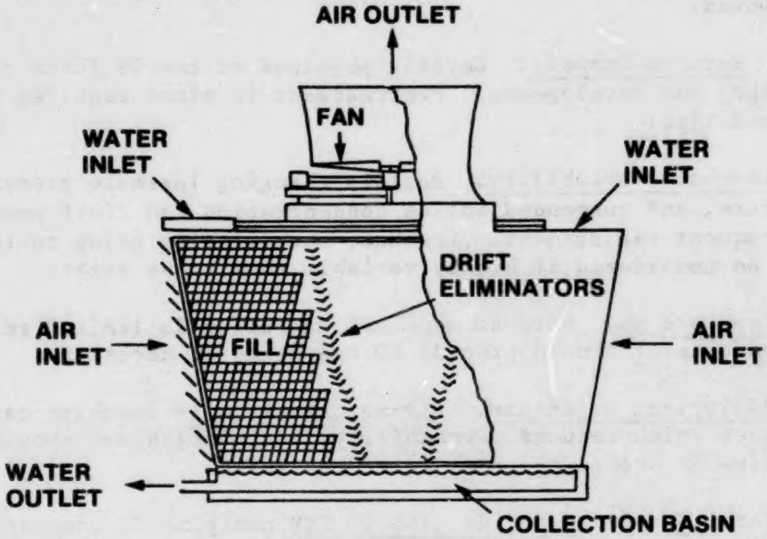
- volatile organic compounds (phenol, vinyl, chloride, etc.);

- water-immiscible compounds (chlorinated hydrocarbons, etc.);

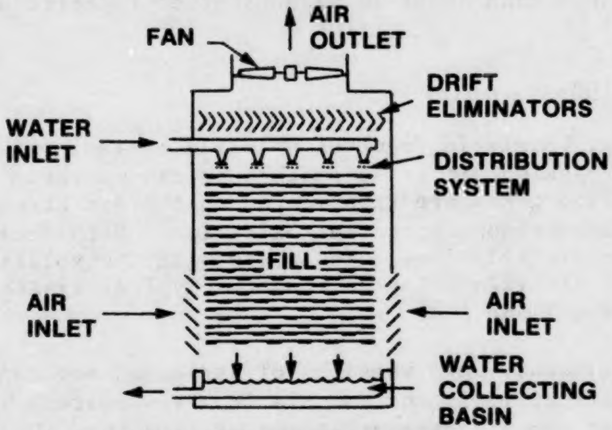
- ammonia; and

- hydrogen sulfide.

Removal efficiencies of volatile organic compounds from wastewaters ranging from 10 percent to 99 percent have been reported (EPA, 1980).



CROSS-FLOW TOWER



COUNTERCURRENT TOWER

Figure 4-7: Air Stripping Towers

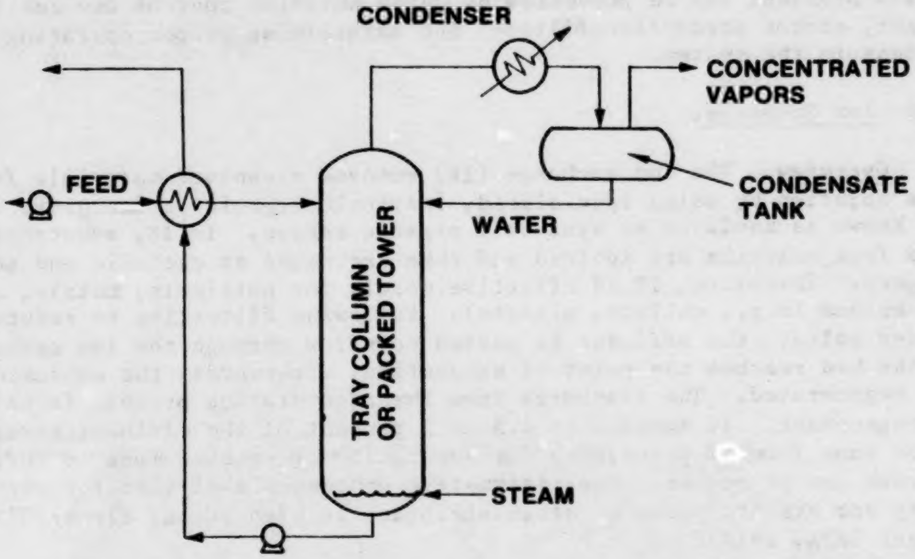


Figure 4-8: Typical Steam Stripping System

c. Limitations. Air stripping has been demonstrated only for ammonia in cooling tower systems. Both air and steam stripping pose potential air pollution problems if volatile organic compounds are present in the leachate. Air pollution problems can be prevented by using emission control devices (e.g., condenser, carbon adsorption filters) and maintaining proper operating conditions in the system.

4.03.10 Ion Exchange.

a. Overview. The ion exchange (IE) removes dissolved materials from aqueous solution by using specialized, insoluble organic or inorganic complexes known as zeolites or synthetic organic resins. In IE, substances to be removed from solution are ionized and then exchanged at cationic and anionic exchangers. Therefore, IE is effective mostly for nutrients, metals, and simple anions (e.g., sulfate, nitrate). Following filtration to reduce suspended solids, the effluent is passed downflow through the ion exchange bed until the bed reaches the point of exhaustion; afterwards, the exhausted bed can be regenerated. The discharge from the regeneration process is called spent regenerant. It amounts to 2.5 to 5 percent of the effluent stream and requires some form of processing for separation of removed ions so that the regenerant can be reused. The alternative processes available for regenerant recovery are air stripping or steam stripping at high pH and electrodialysis treatment (EPA, 1978).

The process for individual beds is batch, but by using multiple beds, continuous operation can be accomplished.

b. Effectiveness. Most inorganic dissolved salts and some organic dissolved salts can be removed by ion exchange. Ion exchange exhibits high ammonia ion removal efficiency; 93 to 97 percent. It is not significantly impaired by temperature fluctuation and unaffected by toxic compounds. Residual ammonium ion concentrations are in the range of 1 to 3 mg/l (EPA, 1978). Performance on other volatiles has not been well documented. Very few installations using large scale ion exchange have been built.

c. Limitations. Theoretically, ion exchange processes are capable of treating TDS concentrations up to 10,000 to 20,000 mg/l. However, practical operations are limited to TDS concentrations less than 2,500 mg/l because of excessive service requirements associated with resin regeneration at higher TDS concentrations.

Ion exchange will only remove specific ions according to resin selection, limiting its usefulness for broad spectrum inorganics removal. Ion exchange is a multistep process requiring use of large amounts of acids and alkalies, precise chemical control to assure economy, and either removal of solid resins or frequent switching of streams. Ion exchange processes thus present more problems in reliability and control than the more continuous thermal or electrical processes.

In the event of human or mechanical errors, the feeding of any form of alkali into the type of saline waters found in most of the United States will result in a high probability of hard scale deposition.

4.04 Runoff and Leachate Treatment.

4.04.01 Overview. Runoff water and leachate produced at the disposal site will vary in quantity and contaminant concentration over time. Runoff water will be produced initially as the site dewaters. During this time period, it can be expected to have a higher contaminant concentration than the runoff water resulting from precipitation after a surface cap has been placed. Leachate from the site will be produced as water percolates through the cover or cap and the inplace dredged material. Although the quantity of the leachate produced will be relatively small, the contaminant concentrations may be high and leachate production will probably persist for the life of the site.

Available data for the characterization of leachate produced from dredged material is very limited. Yu and Chen (1978) found that potential adverse water quality impacts most likely will be caused by the increases of chloride, potassium, sodium, calcium, total organic carbon, alkalinity, ion, and manganese. Field monitoring also detected low concentrations of cadmium, copper, mercury, lead, zinc, phosphate, and nickel. The extent of the potential impact was related to the dredged material's physiochemical properties, site specific ground water hydrogeological patterns, and environmental conditions of the surrounding area. Yu and Chen concluded from trace metal analysis that manganese and iron should pose the greatest water quality problems in upland dredged material disposal. However, leachate quality from dredged material will be highly site specific. Since the data available for dredged material leachate is limited, the remainder of this discussion will concentrate on the treatment of landfill leachate. Landfill leachate will often be of lesser volume and higher concentrations of contaminants than dredged material leachate. As such, dredged material leachate can be expected to be more difficult to monitor and treat than landfill leachate. However, the latter represents the best analogy available for leachate from dredged material.

Depending on the quantity and quality, runoff water can be treated as either as site effluent (4.03 above) or as leachate (4.04.02 below).

4.04.02 Treatment of Landfill Leachate. The treatment alternatives for landfill leachate can be divided into two categories: off-site and on-site treatment. Offsite treatment can be accomplished simply by the addition of leachate to a municipal wastewater treatment plant stream. Wastewater treatment plants are not adversely affected by accepting up to 2 to 5 percent by volume of high strength leachate (Shafer, 1983). Normally a sewer surcharge charge would be required. The option of utilizing a nearby industrial waste treatment plant is also a viable alternative. Although treatment fees can be significant, the reduction of the need for onsite personnel and treatment facilities makes the use of nearby municipal or industrial wastewater treatment facilities an attractive option. This off-site treatment option should be explored for upland sites.

The array of on-site treatment systems used in leachate treatment parallel those commonly in use for wastewater treatment and can be classified as either physical-chemical or biological treatment systems. Due to the wide variation in the composition and biodegradability of leachates from different waste types, no single treatment process or combination of processes can be recommended as optimum for all circumstances. Selection of the best treatment process requires knowledge of the quality and quantity of leachate to be treated and the specific discharge requirements of the site. Treatment systems currently adequate may, due to changes in leachate composition during aging of the landfill or regulatory revisions, be inadequate at some future time. Fluctuations in leachate quality and strength can cause serious problems in maintaining an active biomass for biological treatment or in attempts to automate chemical treatment systems.

a. Biological Treatment. Both aerobic and anaerobic systems have been given extensive bench scale study and both have been found to be effective in removing organics and other constituents from landfill leachates (Shafer, 1983). Full scale treatment systems have almost exclusively used aerobic conditions. In general, conventional activated sludge systems do not work satisfactorily with high strength leachates, making dilution with clean water at the site a requirement. Activated sludge systems studied have required retention times of over 5 days to prevent system failure and to develop maximal removal efficiencies. The only large-scale anaerobic leachate system currently under study in the United States has not proved to be effective due to the low level of biodegradable organic materials in the feed (Shafer, 1983).

Landfill leachate is usually found to be nutrient limiting in phosphorus so that phosphate additions are often recommended to increase system efficiency and reduce retention times. Heavy metal toxicity has not been shown to be a problem in any system yet studied, but lime addition as a pretreatment has been included in several studies to remove metals (Shafer, 1983).

b. Physical-Chemical Treatment. Carbon adsorption or reverse osmosis appear promising for removal of refractory organics. Chemical precipitation, or reverse osmosis may best be used for metal and total dissolved solids removal. Lime addition in the final treatment stage was found to reduce residual organics and metals in activated sludge effluent, but the lime dosages were said to be so large as to be uneconomical. Effluent polishing by carbon adsorption is also effective and may be more economical (Shafer, 1983).

Reports on the use of physical-chemical treatment systems on high COD leachates have concluded that none were feasible unless preceded by biological treatment to reduce the COD. Neither chemical precipitation (using lime or sodium sulfite) nor chemical coagulation (using alum or ferric chloride) were effective in removing oxygen demand. Chemical oxidation using chlorine, hypochlorite, permanganate, or ozone were more effective; but, required prohibitively expensive doses of oxidate for treating leachates (Shafer, 1983).

4.05 Disposition of Treatment Materials. With the exception of ozonation, the treatment processes discussed in sections 4.03 and 4.04 do not destroy contaminants, they simply concentrate them by removal from site effluent, runoff or leachate waters. The concentrated contaminants, often contained in a process sludge or regenerant fluid, must be disposed of in an appropriate facility.

If the sludge is sufficiently contaminated to be classified as dangerous (DW) or extremely harzardous (EHW) waste, it will require handling and disposal as specified in state and Federal regulations. However, in some cases, classification as DW or EHW may not preclude the basic and most common option: dispose of treatment sludges or fluids in the primary disposal site. Disposing of DW or EHW treatment materials in the primary disposal site would require that the site be designed to receive these materials (most likely an upland site).

After the primary site has been closed, treatment materials will need to be transported to an approved disposal facility. As mentioned above, if an industrial or municipal treatment facility is available to process the site leachate, postclosure treatment sludges or fluids would not be a major site consideration.

4.06 Biological Control of Disposal Areas.

4.06.01 Overview. Biological control of disposal areas, as discussed here, refers to isolating contaminated sediments from direct contact with biological organisms. In open-water disposal areas, biological control measures are limited to capping of contaminated sediments and cap monitoring to ensure sufficient thickness to avoid bioturbation of contaminated mate- rial. These measures are discussed above.

For upland and nearshore disposal areas, biological control relates primarily to the period of time after disposal of the contaminated sediments and prior to placement of final surface cap. This period could involve several years, as large disposal sites are frequently filled with materials from several dredging cycles or jobs and over extended time frames. Additionally, sites are frequently allowed to consolidate and dewater prior to placing final surface finishing materials.

After dredged material has been placed in either a nearshore or an upland environment, salt-tolerant plants can invade and colonize the site. In most cases, fine-grained dredged material contains large amounts of nitrogen and phosphorus, which tend to promote vigorous growth of plants on dredged material placed in confined disposal sites at elevations that range from wetland to upland terrestrial environments. In other cases, salt content of the sediment may prevent plant growth for a period of months to a couple years. There is potential for movement of contaminants from the dredged material into plants and then eventually into the food chain.

Animals have also been known to invade and colonize confined dredged material disposal sites. In some cases, prolific wildlife habitats have become established on these sites. Concern has developed recently on the potential for animals inhabiting either nearshore or upland confined disposal sites to become contaminated and contribute to the contamination of food chains associated with the site.

4.06.02 Biological Control Measures. The first step in selecting appropriate biological control measures is the identification of routes and the estimation of rates of contaminant loss due to biological uptake. This information is usually available from sediment testing conducted prior to disposal. The biological control program should be designed in consideration of the potential exposure times, the bioavailability of the sediment contaminants, and the amount and effect of potential uptake that is predicted.

Measures that can be implemented include:

a. fencing to prevent human and large mammal access to the site,

b. pest and plant control by application of biocides, and

c. periodic (daily to yearly) covering programs:

   - roll-back grids to prevent small mammal burrowing,
   - clean soil or sediment layers placed prior to inactive periods, and
   - synthetic liners.

The simplest control measure is the placement of a surface cover thick enough to protect against contaminant uptake in plants and animals. Other control measures are discussed in section 4.02.03.

4.07 Monitoring and Remedial Response.

4.07.01 Purpose and Need. Containment and treatment do not guarantee contaminant isolation in the long term. Present state-of-the-art in disposal of contaminated materials requires monitoring of containment success in order to obtain an acceptable level of confidence. Monitoring parameters and frequency will necessarily vary depending on types and levels of contamination and existing resources and uses that might be impacted by contaminant release. Standards are not available. For this reason, costs are not provided in this report.

Even more important than what and when to monitor is how to respond to monitoring indications. Remedial response options will be substantially different for each disposal method. The potential high cost of remedial response may well make it worthwhile to over design the original containment and treatment facility. Further technical guidelines may be found in state solid waste regulations.

4.07.02 Monitoring Parameters and Frequency.

a. Open-Water. Contaminants can escape from a capped area by diffusion through the cap, convection, and bioturbation. The most practical monitoring measure is checking cap thickness and examining cap integrity. This is done by both remote sensing (bathymetry) and direct sampling (with cores). Coring would not disturb the cap integrity if the cap is comprised of clean sediments that will "self-heal" once the core is removed. Additionally, core samples can provide indication of extent of bioturbation and movement of contaminants through the cap.

Cap integrity should be checked at least four times annually for several years until cap movement rates are established for a given site. After these are determined, annual monitoring should suffice. Stability should also be monitored after severe storms and upon completion of recent disposal and new cap. Contaminant measurements in the core of the cap should be done annually.

b. Upland. Contaminants can escape from liners into ground water. Therefore, observation wells are used to monitor ground water composition. Figure 4-9 shows a typical monitor well network. Sampling of leachate from the underdrains for analysis can be conducted concurrently with well sampling. Diffusion and convection can cause loss of volatile gases through a cap. Gas samples can be collected and analyzed to estimate this loss.

Upland ground water and leachate monitoring frequency depends upon ground water use. If a nearby aquifer supplies drinking water, monthly sampling may be warranted; otherwise, ground water and leachate samples taken four times per year should be adequate. Air samples can be taken concurrently with water samples.

c. Nearshore. Escape of soluble contaminants from the nearshore sites would be more rapid than escape from the upland area due to close proximity to and movement of water. Monitoring contaminant escape into adjacent waters is very difficult and techniques have not been demonstrated in this environment. Shellfish sampling around the site and tissue analysis may provide evidence of contaminant escape. Alternately, placement of recoverable, adsorbent materials (cartridge filter) in a well within the containment dike would serve to concentrate contaminants escaping the site and provide an integrated measure of the contaminant loss (a proven ground water technology). Volatiles monitoring could be done similarly to that for upland sites.

Monitoring should be done annually at first, taking into account seasonal influences on organism bioaccumulation. Volatiles can be monitored four times per year.

4.07.03 Remedial Response.

a. Open-Water. Cap integrity is maintained by addition of more capping material.

b. Upland. First response to excessive loss of soluble contaminants should be activation of leachate collection system and treatment of leachate. Purified leachate can be discharged or reinjected into gravel bedding to maintain positive ground water pressure. If the collection systems fails and excessive ground water contamination appears, detailed site explorations are necessary. These may lead to ground water treatment and/or sediment removal from the disposal site.

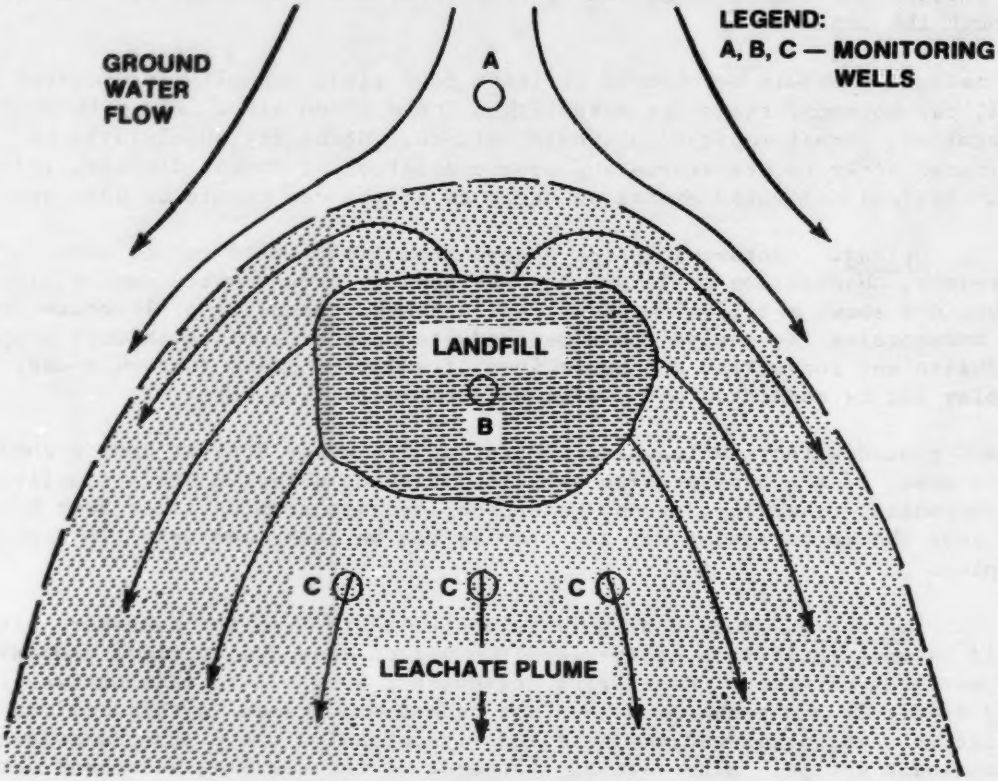


Figure 4-9: Leachate Plume Produced by Upland Landfill Above Groundwater Table and Site Well Monitoring System—Plan View

Volatiles loss via escape of gaseous phase can be retarded by placing a new surface cap.

c. Nearshore. Stopping excessive leakage from nearshore sites could be accomplished by: construction of a new closure berm, dewatering the space between the berms and treatment of leachate collected; construction of slurry walls within containment berms; corrective actions to reduce rainwater infiltration at the surface (improve cap); and/or, moving sediment to another site.

CHAPTER 5.0 COSTS FOR DREDGING, DISPOSAL, CONTROL, AND TREATMENT

5.01 Introduction. This chapter summarizes available information concerning costs of dredging, disposal, control, and treatment of contaminated sediments in Commencement Bay. Costs for dredging and disposal of contaminated sediments are dependent upon the degree of contaminant containment desired. While some cost information is available for specific dredge types, disposal sites, and treatment methods, the costs of many potentially useful or important additions to these categories are not readily available. Therefore, cost estimates for application to Commencement Bay are provided for relative comparison at this stage of planning.

Table 5-1 summarizes the factors affecting costs for dredging, disposal, and control in the Commencement Bay area; tables 5-2 through 5-8 provide the cost estimates. For discussion, general principles affecting costs are described in the beginning of each section and specific costs then follow. Descriptions of the technology being discussed are found in the preceding chapters.

5.02 Dredging Costs.

5.02.01. General Cost Principles. The cost of dredging per unit volume is extremely variable. For example, the cost of mobilizing a dredge will vary with equipment availability and will be amortized into the quantity of material being dredged. As the distance between the disposal site and dredging location increases, the requirement for additional barges, pipeline booster pumps, or hopper downtime will affect cost. Production rates, which can vary greatly for different equipment, physical sediment characteristics, and site conditions, also will affect cost. However, the traditional considerations of production rates and cost must be considered in reference to the objective of efficient removal of contaminants. In some cases, operational conditions that maximize production rates will also improve contaminant confinement (e.g., high solids concentrations for pipeline dredging). In other cases, improved production will result in greater contaminant loss (e.g., hopper dredge overflow).

The dredges themselves are for the most part comparably priced and do not account for most of the cost variability. However, job specific factors can produce substantial cost differences between dredge types. Many of the dredges described are readily available for use in Commencement Bay. The notable exception is the group of special-purpose dredges for which availability could be a major cost factor to be considered.

5.02.02. Hydraulic Dredges.

a. Cutterhead. Hydraulic pipeline cutterhead dredges generally have the widest range of application of dredge types and are usually also among the least expensive methods. Their widespread use and availability is an important cost factor. There are many cutterhead dredges available in the Northwest. Conventional cutterhead dredges are not self propelled but require towboats to move them between dredging locations. Thus, mobilization and setup are major and costly undertakings. A large dredge can cost between

TABLE 5-1

COST FACTORS CHECKLIST

Dredging

- Dredge type and equipment modifications
- Equipment mobilization and demobilization
- Transport distance and vertical lift
- Transport method
- Production rate
- Operational modifications

Disposal

- Site acquisition
- Site information needs
- Site preparation
- Discharge controls (weirs, vertical diffuser)

Control and Treatment

- Flow rate
- Level and type of treatment
- Treatment end-products management (e.g., sludge disposal)

Monitoring

- Types of monitoring
- Frequency of monitoring
- Duration of monitoring
- Remedial response to monitoring indications

TABLE 5-2

TYPICAL DREDGE CHARACTERISTICS AND COSTS [1]

		Size or Capacity	Production Rate (c.y./hr)	Cost Per Cubic Yard ($)
Cutterhead[2]	Pipeline Diameter (Inches)	6	71	5.00
		8	79	4.50
		10	225	4.00
		12	405	3.50
		14	525	2.15
		16	656	1.80
		20	1,024	1.50
		24	1,211	1.35
		30	1,875	1.20
Hopper[3]				
	Hopper Capacity (cy)	3,000 with overflow	1,200	1.39
		3,000 without overflow (if nec.)	600	3.03
Bucket[4]				
	Bucket Size (cy)	5	200	2.50
		15	650	1.60
Suction		-	25-5,000	1.50
Dustpan		-	25-5,000	1.50
Mudcat		-	60-150	1.50
Pneuma		-	60-390	1.05-3.05
Oozes		-	450-650	
Clean-Up		-	500-2,000	1.23

[1] Values shown are representative for Commencement Bay for the cutterhead, hopper, and bucket dredges. Values for other dredges are derived by relation to conventional equipment. Variability may exceed ± a factor of 2-3.

[2] Mobilization costs not included. Price based upon 1-mile transport distance, 20 feet lift, soft sandy silt material, 1983 pricing, and maximum single pass excavation depth.

[3] Based upon 35 c.y. per minute pumping, 8 knots average dredge speed, 5 minutes for disposal, silty sand shoaled materials, 80 percent effective working time, 3 miles distance to disposal site, and cost of dredge operation at $1,300 per hour.

[4] Based upon dredging silty sand with disposal site at a 3-mile transport distance, and 1983 prices.

TABLE 5-3

COST OF DISPOSAL AND CONTROL OPTIONS FOR HANDLING CONTAMINATED SEDIMENTS[1]

Alternative	Cost[2]
Disposal:	
Site preparation	
- upland/nearshore	\$500,000[3]
Weir Construction	
- upland	\$25,000
- nearshore	\$35,000
Diking - imported materials	\$4./c.y.
- onsite materials	\$1./c.y.
Open-water vertical diffuser	
- construction	\$50,000 - \$100,000
- operation	+\$1.-2./c.y.
Offsite material transport	
- truck	+\$.20/c.y./mi
- barge	+\$.20-.25/c.y./mi
Site Control:	
Open-water capping material	\$1.40/c.y.
Liners - soil (volume)	\$16.29-18.29/c.y.
- soil (area)	\$1.81-2.03/ft^2
- synthetic	\$.11-1.50/ft^2
Surface covers	\$1.27-24.20/yd^2
Underdrains	\$2,500/ac
Sediment Stabilization	
- lime	\$10,000-14,000/ac
- dust pallatives	\$1,000-17,000/ac
- water sprinkling	\$2,000/ac

[1] Treatment costs not included because of their dependence on flow rates (see tables 5-7 and 5-8).

[2] U.S. dollars, January 1984.

[3] Average for potential sites identified in Commencement Bay. Includes diking and weir costs.

TABLE 5-4

DISPOSAL SITE PREPARATION COSTS 1/

	Capacity (x1000 c.y.)	Dike and Weir Costs	Preparation Cost per Cubic Yard ($)
Upland Sites			
Puyallup Mitigation	1,000	185	.19
Port of Tacoma "D"	100/1,550 2/	62/275 2/	.62/.18
Puyallup River/Railroad	1,300/3,300 2	505/1,675 2//	.39/.51
Port of Tacoma "E"	1,700	250	.15
Hylebos Creek Nos. 1 & 2	775/1,775 2/	264/1,000 2/	.34/.56
Nearshore Sites			
Middle Waterway	650	303	.47
Milwaukee Waterway	2,160	925	.43
Blair Waterway Outer Slip	892	788	.88
Blair Waterway Middle Slip	945	412	.44
Blair Waterway Inner Slip	600	341	.57
Blair Graving Dock	200	90	.45
Hylebos Waterway No. 1	1,274	615	.48
Hylebos Waterway No. 2	300	295	.98

1/Site acquisition costs not included
2/+20 ft MLLW/+35 ft MLLW

TABLE 5-5

REPRESENTATIVE COSTS FOR SYNTHETIC LINERS

Geotextile Fabrics	\$.11 - .33/ft^2
Membrane Liners*	
Nonreinforced Materials	
30 Mil PVC	0.25 - 0.30/ft^2
30 Mil CPE	0.35 - 0.40/ft^2
30 Mil Butyl/EPDM	0.45 - 0.50/ft^2
30 Mil Neoprene	0.70 - 0.75/ft^2
100 Mil HDPE	1.00 - 1.50/ft^2
Reinforced Materials	
36 Mil Hypalon (CSPER)	0.50 - 0.55/ft^2
60 Mil Hypalon (CSPER)	0.80 - 0.90/ft^2
36 Mil CPER	0.50 - 0.55/ft^2

*Prices from Watersaver, Inc., based upon 400,000 ft^2 installations.

TABLE 5-6

UNIT COSTS FOR SOIL LINER AND SURFACE COVER MATERIALS

Material and/or Method of Installation	1982 Unit Costs
Topsoil (sandy loam), hauling, spreading, and grading (within 20 miles)	\$15.73/c.y.
Clay hauling, spreading, and compaction	\$16.29/c.y.
Sand hauling	\$18.15/c.y.
spreading and compaction	\$9,690-12,200-acre
Cement concrete (4 to 6" layer), mixed, spread compacted on-site	\$7.26-12.10/yd^2
Bituminuous concrete (4 to 6" layer, including base layer)	\$3.81-6.35/yd^2
Lime or cement, mixed into 5" cover soil	\$1.91-2.67/yd^2
Bentonite, material only; 2" layer, spread and compacted	\$1.78/yd^2
Fly ash and/or sludge, spreading, grading, and rolling	\$1.27-2.16/c.y.

Source: EPA, 1982.

TABLE 5-7

TREATMENT LEVEL COSTS COMPARISON FOR NEARSHORE SITE[1]
(30 acres)

Cost Component	Cost ($1,000) Construction	4-Month O&M	Unit Process	Cumulative Total
Dredging 1,000,000 c.y.			1,500	1,500
LEVEL I				
Plain Sedimentation	5,880	50	5,930	7,430
Chemical Clarification	214	220	434	7,864
Filtration				
Option 1 - Pervious Dike	75	5	80	7,944
Option 2 - Sandfill Weir	86	20	106	7,970
				(Assume Option 2 in Level I)
LEVEL II				
Precipitation	869	464	1,330	9,300
LEVEL III				
Carbon Adsorption - Option 1	5,000	495	5,500	14,800
Ozonation - Option 2	1,600	300	1,900	16,700*
				(Assume Option 2 in Level III)
LEVEL IV				
Distillation	47,850	4,452	52,300	69,000
Electrodialysis	24,850	827	25,700	42,400
Reverse Osmosis	28,850	598	29,450	46,150
Ion Exchange	21,350	987	22,300	39,000

*LEVEL III - Total cost includes Option 1 Carbon Adsorption, plus Option 2 Ozonation.

[1] Costs for site control and treatment at a nearshore site can not be directly compared to costs for an upland site: treatment levels contain different site control options.

TABLE 5-8

TREATMENT LEVEL COSTS COMPARISON FOR UPLAND SITE[1]
(80 acres)

Cost Component	Cost ($1,000) Construction	4-Month O&M	Unit Process	Cumulative Total
Dredging 1,000,000 c.y.			1,500	1,500
LEVEL I				
Plain Sedimentation	15,762	50	15,812	17,312
Chemical Clarification	214	220	434	17,746
Filtration				
Option 1 - Pervious Dike	75	5	80	17,826
Option 2 - Sandfill Weir	86	20	106	17,852
LEVEL II				(Assume Option 2 in Level I)
Precipitation	869	464	1,333	19,185
LEVEL III				
Carbon Adsorption - Option 1	5,000	495	5,495	24,680
Ozonation - Option 2	1,600	300	1,900	26,580*
LEVEL IV				(Assume Option 2 in Level III)
Distillation	47,850	4,452	52,302	78,882
Electrodialysis	24,850	827	25,677	52,257
Reverse Osmosis	28,850	598	29,448	56,028
Ion Exchange	21,350	987	22,337	48,917

*LEVEL III - Total cost includes Option 1 Carbon Adsorption, plus Option 2 Ozonation.

[1] Costs for site control and treatment at an upland site can not be directly compared to costs for a nearshore site: treatment levels contain different site control options.

$150,000 and $200,000 to mobilize and demobilize. Large- to medium-sized pipeline dredges should only be considered for use on projects where quantities to be dredged are sufficient to spread mobilization costs.

The operational cost of dredging per c.y. of sediment decreases as pipeline size increases. Table 5-1 shows dredging costs for typical cutterhead dredges. Cost for minimum depth pass excavation can be calculated from tables 5-2 and 6-1 as follows:

$$\text{Cost/c.y. (Min. Pass)} = \frac{\text{(Maximum Depth Pass Excavation)}}{\text{(1/2 x Discharge Diameter)}} \text{ x Cost/c.y. (Max. Pass)}$$

b. Suction and Dustpan. The cost per c.y. for the suction and dustpan dredge are comparable to those for cutterhead pipeline dredges shown in table 5-2. Since all dustpan dredges are located on the Mississippi River at this time, relocation of these dredge types would be an important cost factor.

c. Hopper. Operational costs for hopper dredges range from $700/per hour to over $2,000/per hour. Table 5-2 shows cost and production rates for a hopper dredge working in a Commencement Bay waterway and disposing at the existing DNR open-water disposal site. Since hopper dredges are self-propelled, mobilization and demobilization costs are usually not a significant factor in their use.

d. Special-Purpose. Very little information exists on the cost of using special-purpose dredges, either due to lack of experience or the proprietary nature of these machines. Typically, these dredges are used in relation to material requiring some degree of special handling and predisposal treatment. In these cases, treatment and disposal will represent the bulk of the cost and be the cost controlling factors, not the dredging. Available cost information usually does not make the distinction between dredging and treatment costs. Modifications of conventional equipment, such as the cleanup or refresher dredges, once installed and without considering developmental maintenance costs, would move material at a cost proportional to production rate obtained and comparable to conventional equipment. The pneuma pump, on certain smaller jobs such as berth cleaning, has been shown to be more cost effective than a cutterhead dredge.

5.02.03 Mechanical Dredges. The bucket dredge typically operates at speeds of 30 to 60 buckets per hour. Larger buckets generally resuspend less material per c.y. removed and are more cost effective. Because of this, only medium and large bucket sizes were considered for possible use in Commencement Bay. Table 5-2 compares cost, production rates and dredging depths for medium and large bucket dredges. These dredges are abundantly available in the Pacific Northwest; consequently mobilization costs are not a significant cost factor.

5.03. Disposal Costs.

5.03.01. General Cost Principles. This section describes general principles affecting sediment disposal costs and estimates expenses of implementing disposal at the various pontential sites in and around Commencement Bay. In our evaluation of disposal costs, a number of factors were considered, including site preparation, transportation, and other costs associated with initial or ongoing disposal of sediment. The portion of disposal costs related to transporting the dredged material to a disposal site and discharging and distributing it within the site is included in the costs presented for dredging. Transportation costs addressed in this section relate to modified control of a discharge (e.g., vertical diffusers) and control of return effluent (e.g., weir).

The selected disposal method will have less influence on cost than will the selected particular disposal site, i.e., the key to cost evaluation of disposal is not necessarily the method (open-water, nearshore, or upland), but the location of the particular disposal site and the site preparation needs it might require. Open-water disposal, for which there are normally no acquisition costs, may have a total cost comparable to the other methods due to site preparation costs (if needed), capping volumes necessary (resulting in increased dredging volumes and, hence, total cost), and the greater difficulty in monitoring. Site preparation costs for the other two methods are roughly similar (about $500,000 average in Commencement Bay), although they can vary widely based on specific site conditions. Table 5-3 summarizes costs for the disposal options evaluated.

5.03.02. Open-water Disposal. Open-water disposal costs are normally relatively low for uncontaminated materials. For contaminated material, costs will increase depending upon the selected methods of site preparation and material placement, and upon measures taken to control contaminant release, such as capping and cap thickness. The use of an underwater diffuser increases open- water disposal cost. A construction or acquisition cost of the underwater diffuser is estimated at between $50,000 and $100,000; however, no commercial firms are manufacturing diffusers at this time. A crane and barge would be required to operate the diffuser at the depths required for disposal in Commencement Bay, and this would increase disposal costs by an additional $.50 per c.y. to $.75 per c.y. If materials from a barge or hopper dredge were reslurried and pumped through the diffuser, cost would increase an additional $.75 to $1.25 per c.y. For smaller or one-time dredging projects, it is roughly estimated that the use of the diffuser would increase the disposal cost of cutterhead pipeline dredged materials $1 per c.y. and increase the cost of hopper dredged or clamshell dredged material over $2 per c.y. For larger projects, these costs can be expected to drop.

The costs of capping contaminated material discharged at an open-water disposal site will either be an additional cost (if the cap material is being dredged solely to provide a source of cap material) or part of the overall dredging cost (if the cap material is part of the required dredging).

a. Deep-water Mound. Unconfined mounding of contaminated sediments generates a relatively large surface area to be covered. Assuming disposal of 100,000 c.y. of contaminated material, it is estimated that the cap volume to provide 3 feet of cover would range between three and five times the disposal volume. A volume of four times was selected (400,000 c.y.) to be placed by hopper dredge bottom dump. With a cost of capping material (dredging, transport, and discharge) estimated at $1.50 per c.y., the total cost for this cap would be $600,000.

b. Deep-water Confined. Confining the contaminated material by burial in a depression (possibly with partial underwater diking) results in less surface area requiring cover and allows the use of a vertical pipeline diffuser. For the same 100,000 c.y. disposal, only an additional 100,000 c.y. of clean material was assumed to provide adequate cover. Use of a cutterhead pipeline dredge at a base cost of $1.50 per c.y., and adding to this the increased cost of the diffuser system at $1 per c.y., capping costs would be $250,000. Use of a vertical pipe allows construction of underwater diking at a cost comparable to capping (about $2.50 per c.y.). Diking may totally encircle the site or be in combination with existing natural features (e.g., rock outcrop). This design is more expensive than deep-water mounding due to site preparation but may be easier to cap.

5.03.03 Upland Disposal. Cost of upland disposal will vary according to specific site characteristics. Factors include ownership of the site, amount of site preparation necessary, distance from the dredge site (may include transportation method), and, for the disposal of contaminated materials, the amount of treatment and monitoring required both during and after disposal and capping. For Commencement Bay, weir construction is estimated at about $25,000. Upland sites in Commencement Bay that are in the elevation range of +8 to +12 MLLW may require that all diking materials be trucked to the site. At this elevation, the water table is near the surface and existing native soils may not be sufficient or suitable for dike materials. Granular fill adequate for diking materials is available from the gravel pits on the bluff north of the Hylebos Waterway. The estimated cost of importing materials and dike construction is $4 per c.y.

Where existing ground elevation is higher because of previous fills, the existing surface material may be utilized for diking. Use of existing materials would reduce the cost of diking to approximately $1 per c.y. While coarser fill materials are easier to use for diking, finer soils that can be included in diking will reduce leakage of effluent water through the dike. An associated cost, though one not included in our analyses, involves the ultimate use of the land filled. If disposal can be designed to ultimately allow development to occur, at least some of the initial costs of disposal may be recoverable. This is not possible for open-water disposal.

5.03.04 Nearshore Disposal. The cost factors for confined disposal sites are described under upland disposal. Costs for nearshore disposal site preparation are normally higher than for upland as an adequate foundation for dikes and the weir must be provided. For the weir alone, additional cost was estimated at about $10,000 for a total estimate of $35,000. The primary cost advantage of nearshore disposal over open-water or upland disposal is that nearshore sites are normally located close to the dredging site(s), saving transportation costs. Additionally, most nearshore sites are ultimately planned to be developed so some cost recovery can be anticipated.

5.03.05 Off-site Disposal. The differences between local and off-site disposal involve increased costs for transportation of the contaminated materials to the offsite disposal area and the problems of retaining the contaminants during that transport. The latter problem can be effectively handled by current technologies associated with transportation of hazardous materials; it is, however, expensive. The increased costs would depend upon the transportation mode selected and associated controls and treatments required. Barging of dredged material to an open-water site outside of the Commencement Bay area was considered initially, but was dropped because no likely specific site could be identified based on existing information. Estimated transportation costs for barging would be an addition of approximately $.20 to $.25 per c.y. per mile. Transportation costs for trucking dredged material (but not including dewatering or rehandling charges) was estimated at an additional $.20 per c.y. per mile.

5.03.06 Potential Disposal Site Costs. The following section addresses site preparation costs for the potential disposal sites identified in Commencement Bay. In all cases, site acquisition costs were not investigated. Table 5-4 summarizes disposal site preparation costs.

a. Puyallup River Delta Site. There may be expenses involved in having DNR redesignate the site for open-water disposal. The site is located within 2 miles of most anticipated dredging sites; therefore, transport of dredged material would be minimal. The site's slope could make capping difficult and might necessitate some site preparation in order to confine contaminated sediments.

b. Department of Natural Resources Site. The location of this open-water site places it beyond the most economical pumping distance for pipeline dredges (a booster pump would be necessary). Use of a vertical pipeline diffuser is possible with commensurate cost increase ($1 to $2 per c.y.). If underwater dikes are constructed, a vertical pipeline diffuser would be necessary.

c. Hylebos/Browns Point Site. There may be expenses involved in getting the site designated by DNR as an open-water site due to lack of information about the area. The site is within economical pumping and haul distance for all dredges. Use of a vertical pipeline diffuser is possible ($1 to $2 additional per c.y.) and would be required to construct the underwater dike.

d. Puyallup Mitigation Site. This upland site is located within reasonable economical pumping and haul distance. Existing fill material can be utilized for dike construction at a cost of about $1 per c.y. Estimated diking cost is $160,000 and weir construction is $25,000 for a total preparation estimate of $185,000.

e. Port of Tacoma Site "D". This upland site is well within economic pumping and haul from most potential dredging sites. As existing fill could be used for dike construction. Dike and weir construction for fill to +20 feet MLLW is estimated at $62,000. The same cost to fill to +35 feet MLLW is $275,000.

f. Puyallup River/Railroad Site. This upland site would probably have to be purchased from the owner and the claim by the Puyallup Tribe resolved. Diking and weir costs to fill the site to +20 feet MLLW were estimated at $505,000. The same cost to fill to +35 feet MLLW would be $1,675,000. Given the site location, use of a booster pump for hydraulic dredge disposal may be necessary for some dredging sites.

g. Port of Tacoma Site "E". This upland site is within economical pumping and haul distance from Blair, Sitcum, and Hylebos Waterways. Existing fill material could be used in dike construction; diking and weir costs were estimated at $250,000.

h. Hylebos Creek Sites Nos. 1 and 2. These two upland sites would probably have to be acquired from their owners. The sites are within the economic pumping and hauling distance. Diking and weir construction for fill to +20 feet MLLW was estimated at $264,000 and to +35 feet MLLW at $1,000,000.

i. Middle Waterway Site. Relocation or compensation to waterway users may be required for this nearshore site. It could receive dredged material from anywhere in the harbor economically. Site preparation costs are estimated to total $303,000, including $240,000 for dike construction, $28,000 for slope protection (riprap), and $35,000 for the weir.

j. Milwaukee Waterway Site. Dredged material from anywhere in Commencement Bay could be disposed of economically at this nearshore site. Total site preparation cost was estimated at $925,000, including $716,000 for diking, $174,000 for slope protection, and $35,000 for weir construction.

k. Blair Waterway Slips. All of these nearshore slips could accept dredged material from anywhere in Commencement Bay. Site preparation costs for the outer slip were estimated at $788,000, including $678,000 for diking, $75,000 for slope protection, and $35,000 for weir. Site preparation costs for the middle slip were estimated at $412,000, including $339,000 for diking, $38,000 for slope protection, and $35,000 for the weir. Site preparation costs for the inner slip were estimated at $341,000, including $265,000 for diking, $41,000 for slope protection, and $35,000 for the weir.

l. Blair Graving Dock Site. Preparation costs for this nearshore site were estimated at $90,000, including $50,000 for diking, $15,000 for slope protection, and $35,000 for the weir.

m. Hylebos Waterway No. 1. Preparation costs for this nearshore site were estimated at $615,000, including $480,000 for diking, $100,000 for slope protection, and $35,000 for the weir.

n. Hylebos Waterway No. 2. Total preparation costs for this nearshore site are $295,000, including $200,000 for diking, $60,000 for slope protection, and $35,000 for the weir.

5.04 Control and Treatment Costs.

5.04.01 Control and Treatment Cost Principles. Costs for control features discussed in chapter 4 are summarized below. However, costs for treatment processes are highly dependent on flow rates to be treated. Flow rates will vary depending on the size and type of dredge, the type of site water, and flow rate controls that are available. Therefore, costs of treatment unit processes are not provided in this chapter. Instead, costs are provided for application of these processes to example disposal areas as a way of illustrating relative costs. Site control and treatment measures are combined into these example designs.

Table 5-5 shows the range of synthetic liner costs in upland disposal areas. Representative costs for soil liner and surface cover materials are shown on table 5-6. Placement of a soil liner under water in a nearshore site could increase costs by $1 to $2 per c.y. An underdrainage system for an upland site is estimated to cost $2,500/acre.

There is a limited amount of cost data available for sediment stabilization methods. The following are estimates of cost for the various methods:

- Lime mixed into 5 inches of cover soil would cost from $10,000 to $14,000 per acre.
- Agronomic methods to control dust pallatives include revegetation of the site. Capital costs include area preparation, seeding, fertilizing, and mulching. These costs would be about $1,100 per acre. Operation and maintenance costs would include grass mowing and refertilization.
- The cost for a sprayed asphalt membrane is about $10,000 to $17,000 per acre.
- Soil cement stabilization costs about $15,000 per acre.
- Costs are not readily available for biological decontamination methods.
- Water sprinkling systems cost about $2,000 per acre.

5.04.02 Nearshore vs. Upland Treatment Costs. The following discussion is not intended to represent actual costs for specific sites, but is intended to illustrate the different factors affecting costs for nearshore and upland disposal areas. Several simplifying assumptions are made for costing the two site alternatives. Among these are:

- project size equals 1,000,000 cubic yards;
- upland site is 80 acres;
- nearshore site is 30 acres;

o 24-inch hydraulic pipeline dredge operating 10 hours per day for 4 months;

o site control required for upland site includes covers, liners, and underdrains (leachate collection);

o site control for the nearshore site includes only a soil liner and cover;

o levels of treatment are applied only to effluent during disposal operations, and to runoff and leachate treatment;

o levels are additive for costing purposes; and

o postclosure facility monitoring and maintenance costs are not included.

Costs are current to January 1984 price levels. Pricing information which was obtained from published reports and technical manuals has been updated to current levels based on Engineering News Record (ENR) construction cost escalation factors. Cost of salvage was assumed to equal cost of demolition at project completion. Contingencies represent allowances for unforeseen conditions and factors not known at this level of investigation. A larger contingency factor was applied to nearshore plain sedimentation than to upland plain sedimentation because of the greater potential for unknown costs associated with work below the water table. Operation and maintenance costs include the estimated cost for labor, chemicals, testing, and energy requirements for the particular alternative.

While cost of treatment systems can be compared within each of the representative sites, it must be emphasized here that cost comparisons between sites is not possible for several reasons. First, costs are based on placing the same quantity of dredged material in sites of different capacity. Discharging additional material into the larger site would reduce the cost of treatment per c.y. of material discharged. Second, costs for treatment at the upland site include several treatment methods that cannot be implemented at the nearshore site without site dewatering. Dewatering would require extraordinary and extremely expensive construction techniques and is, therefore, not considered here. Third, foundation material in the nearshore zone may not be adequate to support the necessary diking. Seismic potential, mud foundations, and tidal fluctuations can threaten dike stability. As a result, construction in the nearshore zone has a higher risk of failure. Fourth, equivalent treatment in each site would produce lower containment of contaminants in the nearshore site due to the factors operating on contaminant mobility and the limited site control relative to upland sites.

Costs based on the above assumptions are summarized below. Detailed cost tables and supporting calculations used to develop treatment level costs are found in appendix 3.

- o The costs for site control and treatment in the nearshore site evaluation example are shown in table 5-7. The costs range from $7,970,000 (Level I) to $69,000,000 (Level IV).

- o Upland disposal area site control and treatment costs are summarized in table 5-8. The costs range from $17,852,000 (Level I) to a maximum of $78,882,000 (Level IV).

The cost of plain sedimentation represents the majority of treatment costs compared to chemical clarification, filtration, and metals precipitation. The addition of these latter treatment methods may be relatively cost effective measures of obtaining substantial additional contaminant removal. For organic contaminants, Level III treatment provides high removal efficiency at a cost increase of 40 (upland) to 80 (nearshore) percent. Level IV treatment of the site effluent would be unlikely for several reasons. First, organic contaminants are a major part of the sediment contamination in Commencement Bay and Level III treatment is highly effective for organic contaminant removal. Second, Level IV treatment of the high rate effluent flow represents a substantial additional cost. Third, Level IV treatment processes have not been well documented for high rate application to multiple-contaminant slurries. As a result, Level IV treatment is only a likely consideration for site runoff and leachate, where the alternative of using an existing municipal or industrial facility may be available. Of the Level IV treatment systems, distillation is the most expensive, best documented, and best performing process available.

5.05 Other Cost Factors. Since many of the cost estimates provided in this report are based on illustrative examples, the sensitivity of costs to quantity of material being dredged and degree of contamination is briefly discussed here. The key to the effect of job size on cost is the mobilization, construction or other "up-front" costs. These costs are spread out over the quantity of material handled. For dredging, the mobilization of a large dredge can add 7.5¢/c.y. on a large dredging job (2 million c.y.), but can easily add up to $1.50/c.y. for a small job (100,000 c.y.). For disposal, spreading the costs of diking, weir construction, and land acquisition/development is much the same idea as for dredging. With control and treatment, the flow rate will have a major effect on costs, but the substantial construction costs of many of the treatment facilities can be spread out over increased quantities. In conclusion, there are strong economic incentives to centralize disposal and treatment facilities and maximize their use.

Commencement Bay contamination is predominantly "low saturation" in the chemical sense, that is, sediment contaminant concentrations are mostly less than 50,000 ppm in sediments. Once it is determined that a treatment or control is needed (i.e., criteria are exceeded), treatment measures can be expected to be equally as effective with twice the contaminant concentration as with half the concentration observed in the sediments. The cost of treatment is, therefore, relatively independent of contaminant concentration, once criteria have been exceeded.

CHAPTER 6.0 DISCUSSION AND CONCLUSIONS

6.01 Introduction. Previous chapters provide a description and evaluation of alternative dredging, disposal, site control, and treatment methods and their costs for use with contaminated sediments. This chapter compares and discusses these methods, presenting those conclusions that can be formulated at this stage of planning for Commencement Bay. First, preferred dredging methods and possible tradeoffs for various types of sediment contamination are addressed. Disposal methods are ranked in terms of the major factors that would influence decisions on disposal of contaminated sediments. Likely application of contaminant treatment techniques in Commencement Bay is presented. Second, the relative contaminant loss or confinement obtained during each stage of the handling process (dredging, disposal, control, and treatment) is discussed. Third, disposal sites are evaluated and recommendations on preferred or most appropriate sites for near-term consideration are presented. Fourth, information needs and data gaps for handling of contaminated sediments are identified. Research or tests that merit priority consideration at this time are discussed.

6.02 Dredging Methods.

6.02.01 General. Operating characteristics of hydraulic and mechanical dredges are summarized in table 6-1. Cost and resuspension values, while representative to the extent that they fall within normal ranges for a given dredge, are derived from various sources with unique conditions. Therefore, these values have not been normalized and comparisons between dredging methods must acknowledge their variability. In terms of sediment resuspension at the dredge site, this table illustrates that special-purpose hydraulic dredges produce less resuspension than conventional hydraulic dredges, and, with the exception of hopper dredge overflow, conventional hydraulic dredges produce less resuspension than mechanical dredges.

In terms of slurry water that may require treatment at the disposal site, mechanical dredges do not produce a slurry, conventional hydraulic dredges produce abundant slurry water, and special-purpose dredges fall somewhere in between. In terms of cost, dredges are for the most part comparably priced. However, job specific factors can produce substantial cost differences between dredge types. Many of the dredges listed in the table are readily available for use in Commencement Bay. The notable exception is the group of special-purpose dredges for which availability could be a major cost factor to be considered.

Until recently, many of the special-purpose dredges have had lower production rates than conventional equipment. This is still true for several of these dredges, but newer equipment such as the refresher and oozer appear to have production rates comparable to conventional hydraulic dredges. For barge or hopper-hauled dredged materials, production will vary depending on proximity of the disposal site, but it is usually less than what can be obtained by a continuously operating cutterhead dredge.

TABLE 6-1

SUMMARY OF DREDGE OPERATING CHARACTERISTICS

	Percent Solids in Slurry or Transported Material by Weight[a]	Sediment Resuspension Above Background (mg/1)[b]		Approximate Range of Production Rates (c.y. yd/hr)	Dredging Depths (ft)		Vertical Dredging Accuracy (± ft)	Horizontal Dredging Accuracy (± ft)	Availability
		near bottom	near surface		Minimum	Maximum			
Bucket	up to 100%	106	134	30-600	0[d]	150[e]	2	1	Pacific Coast
Suction	10-15%	--	--	25-5,000	5-6	50-60[f]	1	2-3	Pacific Coast
Dustpan	10-20%	--	--	25-5,000	5-14	50-60[f]	1	2-3	Mississippi River
Cutterhead	10-20%	35	134	25-5,000	3-14	12-65[f]	1	2-3	Pacific Coast
Hopper	10-20%	272[g]	627	500-2,000	10-28	65[f]	2	10	Pacific Coast
Mudcat	10-40%	145	500	60-150	11	15	1	1	Pacific Coast
Pneuma	up to 80%	4	23	60-390	0[d]	150[e]	1	1	Chicago, Illinois
Oozer	up to 80%	0	--	450-650	-	100-150	1	2-3	Japan
Clean-Up	30-40%	2.6	4	500-2,000	5-10	60	1	2-3	Japan
Refresher	30-40%	--	13.5	200-1,300	20	60	1	2-3	Japan

NOTES:

a - Percent solids shown are normal working ranges.
b - Resuspension values shown are considered representative. However, very wide ranges are reported.
c - Cost values shown are representative of Commencement Bay for the cutterhead, bucket, and hopper dredges. Values for other dredges are derived by relation to conventional equipment. Variability may exceed ± a factor of 2-3.
d - Zero if used alongside of waterway; otherwise, draft of vessel will determine.
e - Demonstrated depth; theoretically could be used much deeper.
f - With submerged dredge pumps, dredging depths have been increased to 100 ft or more.
g - Value shown is average at 3 feet below surface.

Hydraulic dredges produce less solids resuspension at the dredging site and have a higher removal efficiency for liquid and solid phases than do mechanical dredges. Hydraulic dredges with passive heads (e.g., suction, pneuma, etc.) and shrouded heads (e.g., refreshers, mudcat, etc.) produce less resuspension than do exposed, active heads (e.g., cutterhead). However, use of a hydraulic dredge to obtain high removal efficiency at the dredging site involves a tradeoff requiring consideration of slurry water and sediment consolidaton at the disposal site.

Different dredging methods appear more appropriate for certain contaminant classes. For loss of volatile contaminants during dredging, mechanical dredges will likely perform better than hydraulic dredges. For sediment-bound contaminants, greater removal is obtained by hydraulic dredges than by mechanical dredges and appropriate technology exists for control of solids at the disposal end. Soluble contaminants can be removed more efficiently by a hydraulic dredge, but are difficult to control at the disposal end and treatment of the effluent water may be required.

Most projects are likely to contain all three types of contamination, confounding a decision on appropriate dredging technique. In terms of overall contamination, sediment-bound contaminants usually represent the bulk of the contamination, suggesting use of hydraulic equipment for maximum recovery and extraction efficiency. The amount of volatiles that may be lost during dredging are not likely to be a source of major concern in many projects. Therefore, as the types and amount of soluble, or easily solubilized, contaminants increase in a sediment to be dredged, greater consideration should be given to the relative cost and environmental impact of mechanical dredging with watertight equipment to that of hydraulic dredging and water treatment at the disposal site. This evaluation is likely to be the key to selecting a dredge for a given contaminated sediment.

A variety of equipment modifications are appropriate for dredging contaminated sediments. Many of the practices that increase production of a hydraulic dredge will also reduce sediment resuspension and contaminant loss. The walking spud and ladder pump are prime examples; however, their availability is a function of the original dredge design, which may limit their use in Commencement Bay. Production meters installed in the pipe will contribute to reduced resuspension and are readily available and adaptable to existing equipment. Use of large, watertight buckets will substantially reduce sediment resuspension and loss of interstitial water during mechanical dredging.

Operational modifications to be considered for hydraulic cutterhead dredges include minimizing cutter revolution speed, controlling swing speed, and not overdigging the maximum cut depth. Additional research is ongoing to quantify the effect of these practices. The problem of limiting the environmental impact of dredging contaminated sediments through reducing resuspension of sediments is being addressed by the WES of the Corps of Engineers under a research program known as the Improvement of Operation and Maintenance Techniques (IOMT) program. For hopper dredges, operating in sandy silts or silty sands without overflow can have a significant impact on cost. Therefore, it may not be practical to use a hopper dredge for projects with high concentrations of soluble contaminants. For mechanical dredging, sweeping the bottom with the bucket and digging fine-grained sediments from underneath (heavy buckets penetrating through soft surface materials) are practices to be avoided in contaminated areas. For most operator controls or operational modifications, serious consideration should be given to hourly rental of dredging equipment rather than bidding in order to maintain control of project costs and better define cost factors during first-time use of modifications.

6.02.02 Selection of a Dredge Type. Short-term losses of soluble contaminants represent the key in selecting dredge type. These losses can be estimated by assuming a slow rate of contaminant transfer between phases during dredging and using a modified elutriate test. For hydraulic dredging, test results are used to predict weir concentrations (total and dissolved) expected for a given site. Predicted values can be compared against decisionmaking criteria with or without consideration of dilution in the receiving waters. It is more difficult to predict losses for mechanical dredging. Bucket size, sediment characteristics and other job-specific factors will influence the actual losses in the field. As a usual rule, within the options that are generally considered for large-volume, low-level contaminated sediments dredging, hydraulic dredging with particulates control will likely provide greater confinement per given cost than will mechanical with watertight equipment for situations where a low percentage of the contamination is soluble. As the percentage of soluble contaminants increases, the "confinement-per-cost" indicator will begin to favor the mechanical approach.

However, when considering high-level contaminated sediments, the greater extraction and transport efficiency of hydraulic dredging is an important factor. Overall, the technology for addressing contaminated sediments is better known for hydraulic dredges than for mechanical dredges.

Selection of a dredge requires consideration of all the factors mentioned in paragraph 2.01 and of the disposal and treatment options available. Several dredges may be able to meet criteria by employing one or many of the available dredging techniques. Therefore, identification of the criteria that are to be met is the first and most important task in selecting appropriate equipment.

6.03 Disposal Methods. Evaluation of disposal methods with the idea of defining the appropriate and most efficient means of confining contaminants in the long term is difficult. Contaminants gradually will move back into the environment from wherever they are placed. The factors that influence the speed with which they will release from the disposal site are the mobility of the contaminant, the phase with which the contaminant has associated itself in the sediment (gas, liquid, solid), and the physical/chemical environment into which the contaminant has been placed. Given that most projects will contain more than one class of contaminants, the evaluation becomes complex and variable.

The key considerations involved with disposal method effectiveness are:

- the class of contaminants of concern,

o the similarity of the disposal site conditions to in situ conditions, and

o the number and magnitude of transport mechanisms operating at the disposal site.

Two final considerations acknowledge the impossibility of permanent contaminant retention:

o the degree of control or treatment possible to intercept migrating contaminant fractions, and

o the risk of significant adverse effects from contaminants released by the disposal method.

Table 6-2 provides the major evaluative factors pertinent to disposal methodology and rates the three general disposal methods against those factors.

It is important to know what classes of contaminants are associated with the sediment, what phase the contaminants are associated with in the sediments, and how they are partitioned between phases in situ in order to predict long-term mobility. In general, leaving, or disposing of, contaminated sediments

TABLE 6-2

COMPARISON OF DISPOSAL METHOD EFFECTIVENESS

Disposal Method	Geochemical Effect on Contaminant Mobilization	Magnitude of Contaminant Transport Mechanisms	Available Control/ Treatment Options	Environmental Risks From Contaminant Release
Open-Water, capped	Low	Diffusion: High Convection: Medium Bioturbation: Varies Erosion: Medium	Few	Low due to dilution (Resource risk)
Upland, confined	High	Diffusion: Low Convection: Low Volatilization: High Bioturbation: Varies Erosion: Low	Many	Varies by contaminant (Human health risk)
Nearshore, confined	High in Unsaturated Zone; Medium in Saturated Zone	Diffusion: High Convection: High Volatilization: High Bioturbation: Varies Erosion: Low	Some	Medium (Human health & resource risks)

in a chemical environment as close as possible to their in situ state favors contaminant retention (especially metals). However, placing the sediments into different, or into shifting, physical or chemical environments (upland and nearshore) will encourage some contaminants to move between phases. Geochemical changes associated with air and oxygen in these disposal sites can change sediment pH (mobilizing metals) and alter sediment organic carbon (mobilizing organics). For organic contaminants, the influence of these geochemical changes on contaminant mobility may be outweighed by the effect of water exchange occurring at the site. It is also important to note that while contaminant mobility and release can serve to define disposal method effectiveness, release of contaminants will have different environmental effects in different disposal sites (i.e., greater mobility at one site may be less damaging than lesser mobility at another site).

Transport mechanisms have been identified and explained in chapter 3 for the several disposal methods and designs. Open-water sites, especially those in deep water, have fewer mechanisms (air is absent) than upland sites. Nearshore sites have the most transport routes available and are located in a very active environment; therefore, nearshore disposal is the least preferred method from a contaminant confinement point of view.

In general, contaminants bound tightly to sediments are the easiest to handle and contain. Disposal method considerations involve maximizing containment of solids within the disposal site. Upland and nearshore disposal offers the greatest potential for retaining dredged material, whether hydraulically or mechanically dredged. Open-water disposal, because of depth and currents, allows some fraction of the material placed to escape. Since the material that would normally escape is fine-grained, and more typically associated with chemical contaminants, open-water disposal is less efficient at accepting discharges of contaminated sediments. There are other considerations, however. Aerobic and unsaturated conditions favor release of heavy metals from sediment surfaces into solution. Sediments placed in upland and in the unsaturated nearshore disposal sites would be subjected to chemical stresses (oxidation, pH decrease, activation of other compounds) due to the less stable (in the long term) environment. Contaminant fractions would release as gas or into solution and migrate along seeps or leach into ground water. For heavy metals, disposal in open-water eliminates the conditions favoring release and aids retention. However, contaminated sediments rarely contain only heavy metals. Though many of the organic contaminants found in Commencement Bay are relatively hydrophobic and have high sorption coefficients, there is no known way to keep organics bound to the sediment, and all are somewhat soluble. Placing these compounds in saturated conditions with high water exchange greatly favors contaminant mobility. In these terms, the nearshore has greater water exchange than the upland, and upland has greater exchange than open water.

Volatile contaminant fractions may be lost during dredging or be released only under unsaturated conditions. The key to the mobility of volatiles is the surface area and time exposed to air. Material that has been hydraulically dredged will probably have lost all in situ gases by the time it is placed in the disposal site. Slurry placed into an open-water site may still contain a small percentage of entrained gases that will release until the site is capped; mechanically dredged material will still retain most of its in situ gases. Once capped, the stable, saturated conditions underwater will result in losses of volatiles about an order of magnitude less than the other disposal methods due to less air exchange. Sediments placed in upland disposal sites will drain and volatilization will occur. Disposal in nearshore environment will result in greater release from the unsaturated layer than the saturated layer. Mechanically dredged materials that require rehandling (for transport to or within the disposal site) will tend to lose volatiles more readily than slurried sediments or than sediments that are not rehandled. Over longer periods of time, in situ gases will likely build up in the sediments and provide a mechanism for loss of volatiles. However, the amount of volatiles lost is not likely to be a source of major concern for most projects.

Soluble contaminants, or contaminants with the greatest potential to go into solution under certain conditions, are of more concern because these are less readily contained. Soluble contaminants in situ at the time of disposal will be lost if hydraulically discharged in open water, or may require treatment as effluent from upland or nearshore confined sites. In the effluent, these contaminants will have been diluted by the volume of new water slurried. Mechanically dredged sediments will have retained more of their interstitial water and there will be less quantity to treat; although contaminant concentrations will be higher. In the longer term, contaminated sediments placed in open water will lose their soluble fraction to diffusion and convection; although this release will be gradual due to the reduced magnitude of transport mechanisms. Materials placed in upland disposal sites also will tend to release their soluble fractions over time. Due to the more active physical processes (precipitation, ground water infiltration, etc.) and the unstable chemical environment, this release will be more rapid than in open-water; however, it also will be more concentrated and easily intercepted. The nearshore environment is the most active, having all of the transports of the uplands and the addition of much more active water exchange than in the open water due to tidal activity.

Therefore, in terms of contaminant retention, disposal method selection is more a matter of controlled release than total confinement. Control of the releases and/or concern with the effects of the release must be considered. Open-water disposal allows for very limited control of releases other than cap or liner thickness. This retards contaminant mobility and encourages a constant, gradual release to the overlying water body once the cap has been saturated by the migrating contaminants. The levels of contaminant concentration released will be low and will be diluted by the overlying water. The risk of significant damage in this environment is low and would not likely affect human health. Upland disposal, on the other hand, allows for the greatest control, through design considerations, monitoring capabilities, backup contaminant intercept systems, and treatment facilities. Environmental risks incurred may be higher than in open-water because of potential human health concerns. The nearshore disposal option does allow for some greater control of contaminants than in open water, but many fewer than are available in an upland situation. In addition, the risks to the environment and to human health are much greater than in open water, and in most situations, are greater than at an upland site. Looking ahead to development of criteria for appropriate disposal methods, the interplay of site control and contaminant mobility suggests, as a generalization, that nearshore sites should receive the low-level contamination, open-water sites the low-to-medium level contamination, and upland sites the high-level contamination.

6.04 Site Control and Treatment Methods. The applicability and potential use of various control and treatment alternatives for contaminated sediments in Commencement Bay are shown in table 6-3. This table illustrates that in going from upland to nearshore to open-water disposal, the degree of site control and the number of available treatment options decreases. This decreasing control is translated into reduced opportunities to design additional treatment measures that would prevent sudden or accelerated contaminant release into the environment and/or to avoid the extreme expense of sediment removal and relocation.

As with dredging and disposal, criteria must be known before treatment recommendations can be made. It is logical to assume that disposal of contaminated material in any area without proper treatment and control could result in rapid return of the contaminants to the environment. However, the simple removal of the contaminated sediment from its present location to a new location may produce sufficient increased isolation from, or reduced contaminant loss to, the environment to obtain a net beneficial result. (Note that the exact opposite is also possible.) But from the management perspective that a rapid loss of contaminant "in hand" (dredged out of the aquatic system) represents a lost opportunity at best and an eventual return to existing deteriorated conditions at worst, the uncontrolled and untreated loss may not be acceptable. As environmental criteria require more isolation, greater confinement and less/slower return, treatments exist that can be added to achieve these standards. Federal and state regulations also provide technical guidelines for design of site controls and monitoring of site containment (e.g., State of Washington proposed solid waste regulations). These guidelines should be reviewed prior to selection of appropriate site design.

Presuming that eventual criteria require placing only low-level contamination in nearshore sites, up to medium-level contamination in open-water sites, and the high-level contamination in upland sites, certain implications to treatment levels are foreseen. All control and treatment options labelled as "likely" for potential use (table 6-3) are foreseen as being necessary for respective upland, nearshore, or open-water sites. In addition, as contamination levels approach the higher range of those allowed for each disposal method, options such as cap bioturbation monitoring (for open water), carbon adsorption treatment (for nearshore) and dissolved solids removal from leachate and runoff (for upland) become more probable. These practices should result in contaminant confinement and removal that is acceptable and meets criteria in most cases.

6.05 Relative Containment During Dredging, Disposal, Control, and Treatment. Loss of contaminants during handling of contaminated sediments will occur from all of the three phases of the sediment with which contaminants are associated: solids (sediment), water, and gas. These losses can occur during dredging and disposal, and in the short and long term. For the majority of

TABLE 6-3

APPLICABILITY AND POTENTIAL USE OF VARIOUS CONTROL AND TREATMENT ALTERNATIVES FOR CONTAMINATED SEDIMENTS IN COMMENCEMENT BAY (NA = Not Applicable)

Disposal Method:	Upland Disposal		Nearshore Disposal		Open-Water Disposal	
Potential Use:	Likely	Less Likely	Likely	Less Likely	Likely	Less Likely
Liners	synthetic, soil			soil	NA	NA
Drains	leachate drains		NA	NA	NA	NA
Capping	synthetic, soil		synthetic, soil		sediment	
Sediment Stabilization	liming, pallatives	sprinkling	liming, pallatives	sprinkling	NA	NA
Suspended Solids Removal	sedimentation, clarification, filtration		sedimentation, clarification, filtration		NA	NA
Removal of Solubles	precipitation, adsorption	ozonation	precipitation	adsorption, ozonation	NA	NA
Dissolved Solids Removal		distillation, RO, ED, IE		distillation, RO, ED, IE	NA	NA

Table 6-3

TABLE 6-3 (con.)

Disposal Method:	Upland Disposal		Nearshore Disposal		Open-Water Disposal	
Potential Use:	Likely	Less Likely	Likely	Less Likely	Likely	Less Likely
Volatiles		stripping		stripping	NA	NA
Biological Control	fencing, sediment cover	biocides	fencing, sediment cover	biocides	NA	NA
Monitoring	leachate, ground water	volatiles	berm, ground water	volatiles, shellfish	cap integrity, cap contaminants	cap bioturbation
Remedial Response	leachate treatment	ground water treatment, sediment removal	slurry wall	dewatering berm, sediment removal	add cap materials	
Total Number of Available Options	17	11	11	13	4	1

cases, the largest fraction of the contaminants will be bound to sediments, and the water will contain greater numbers and levels of contaminants than the gas phase. Since volatiles present in the gas phase will rarely present a concern, and since control of sediment particles is relatively well understood and developed, the key to most projects will be the types and amounts of soluble or easily-solubilized contaminants present. Handling of soluble contaminants presents the greatest technical difficulties and can involve the greatest treatment costs.

For hydraulic dredging, the relative importance of losses at various times and from various phases during the sediment handling process is shown below, listed in order of decreasing importance.

(1) short-term loss of sediment and water,

(2) long-term loss of water,

(3) short-term loss of volatiles,

(4) long-term loss of volatiles, and

(5) long-term loss of sediment.

For mechanical dredging, (1) and (2) may be equally important, as more easily solubilized contaminants are retained and available for possible long-term loss from the dredged material.

For hydraulic dredging, disposal will normally result in greater short-term loss of sediment and water than will dredging. Mechanical dredging can result in greater loss at the dredging site than at the disposal site. Where treatment is not done or is not available, long-term loss of water can be more important in upland situations than short-term losses due to the higher contaminant concentrations that are possible in the long-term discharges. For volatiles, short-term losses may be equivalent to long-term volatilization if *in situ* gas volumes are low. For open-water disposal, long-term sediment losses can be more important than losses of volatiles.

The influence of sediment contamination on dredging, disposal, control, and treatment decisions will be keyed to the relative magnitude of potential contaminant releases and to the potential impacts of these losses. Based on the above ranking of importance, short-term sediment and water loss during disposal will be the usual first consideration and the basis for selecting disposal method and treatment level. Concurrently, but on a secondary basis, the contribution of dredging to this loss should be evaluated. The next, subsequent step should be selecting appropriate treatment, monitoring, and remedial response to address long-term loss of waterborne contaminants. Consideration of items (3)-(5) above would depend on sediment and site-specific conditions.

Selection of dredging equipment and design of a disposal site for a given contaminated sediment first require the application of specific tests to assess contaminant phase partitioning and behavior, to estimate contaminant release at various points during the handling process, and to predict contaminant effects under various disposal conditions. Test results are then compared to predetermined standards or reference points (decisionmaking criteria, see section 1.05) to determine where predicted contaminant behavior will require some form of restriction or control. The purpose of the necessary restriction(s) is to reduce (or eliminate) the concern behavior to an acceptable level, thereby providing maximum containment and minimum release of contaminants. Selecting an appropriate restriction method often requires additional sediment testing as part of project design.

Thus, a given sediment from the Superfund site may undergo three different test sequences:

a. testing to determine in-place hazard (is it a "problem" sediment?),

b. testing to determine if restrictions are required to dredge and dispose the sediments in various disposal environments, and

c. testing to select and design the necessary restrictions.

The preceeding sections of this report display and compare the basic options available for design of a restriction or control. Testing methods and decisionmaking criteria are being developed by others (see section 1.05).

6.06 Disposal Sites. The specific disposal sites identified and discussed in chapter 3.0 were evaluated and the results are tabulated in tables 6-4, 6-5, and 6-6. This evaluation is based on available data and the professional judgements of those involved in preparing this report. Telephone and personal contacts were made with responsible officials with the Port of Tacoma, city of Tacoma, city of Fife, Pierce County, Puyallup Indian Tribe, State of Washington, and others. These contacts were not intended to be a comprehensive solicitation of concerns associated with dredging and disposal of contaminated sediments in Commencement Bay, but were instead intended to identify potential disposal sites and to obtain preliminary views on major concerns related to these sites. Not all landowners were contacted as to the availability of their lands, nor were assessments of the value of those lands made. The objective of this evaluation is to develop a reconnaissance level ranking of sites that could receive contaminated dredged material. Those sites that rank "best" are not necessarily to be considered "recommended;" however, they show the best promise for more detailed evaluation leading to a recommended site.

For open-water disposal sites, ease of capping was used as an evaluation factor rather than cost of site preparation. Site preparation of open-water sites would simply be an extension of dredging, that is, underwater dikes could be constructed using clean sediments dredged during the course of navigation maintenance. For this factor, the Hylebos/Browns Point site ranks highest since it has the best potential for burial containment. The DNR site

TABLE 6-4

EVALUATION OF OPEN-WATER DISPOSAL SITES

Site	Availability	Distance	Capacity	Potential Capping	Impacts to Habitat
Puyallup River Delta	0[a]	+	+	-[b]	0
DNR	+	-[c]	+	-	+
*Hylebos/Browns Point	0[a]	+	+	+[b]	?

+ Positive - Negative 0 Neutral ? Information Needed

[a] DNR would have to designate site as available.
[b] Some site preparation might be required.
[c] Beyond pipeline pumping, acceptable for barge and hopper.
* Further evaluation is recommended at this time.

would have to employ the mounding technique in extreme depths. The Puyallup River delta is very unstable; capping and containment may be impossible over the long term. Only the DNR site is currently designated as approved for open-water disposal; however, depending on a variety of considerations, either or both of the other sites could be designated as well. Capacities are essentially unlimited at all sites. The Puyallup River delta is closest to the potential dredging sites; Hylebos/Browns Point is second. The DNR site is outside the most economical pumping distance for Commencement Bay sediments; although it is acceptable for barges and hopper dredges. Because the DNR site has and is currently receiving dredged material on a periodic basis, additional adverse environmental impacts would be fewer. The instability of the Puyallup River delta suggests that unacceptable impacts on benthic resources would not occur, but that same instability renders capping of contaminated sediments difficult. Little is known about the Hylebos/Browns Point site; although it may be important bottomfish habitat. Further evaluation of the Hylebos/Browns Point site is recommended because of the potential for more complete containment of sediments. No further evaluation is recommended for the Puyallup River delta.

Upland disposal sites are highly varied within the Commencement Bay area. Depending on the volume of contaminated sediment that requires removal and disposal, one or more upland sites may ultimately be determined necessary. In addition, individual dredgers may encounter small volumes of material that could be disposed of upland, but timing of dredging, need to fill the site for development, or other considerations may make use of a small site appropriate.

TABLE 6-5

EVALUATION OF UPLAND DISPOSAL SITES

Site	Availability	Distance	Capacity	Costs[a]	Impact to Habitat
Puyallup Mitigation (+35 feet)	-	+	+	+	?[b]
*POT "D"					
(+20 feet)	+	+	0	-	+
(+35 feet)	+	+	+	+	+
*Puyallup River/ Railroad					
(+20 feet)	0	+	+	0	-
(+35 feet)	0	0	+	-	-
POT "E" (+35 feet)	+	0	+	+	+
Hylebos Creek #1 & #2					
(+20 feet)	?	0	0	0	-[b]
(+35 feet)	?	0	+	-	-[b]

+ Positive - Negative 0 Neutral ? Information Needed

[a] Site preparation costs divided by cubic yard capacity of the site.
[b] Agency concerns anticipated.
* Further evaluation recommended at this time.

TABLE 6-6

EVALUATION OF UPLAND DISPOSAL SITES

Site	Availability	Distance	Capacity	Costs[a]	Impact to Habitat
Middle WW	-	O	O	+	O
*Milwaukee WW	+	+	+	+	O
*Blair WW Slips	+	+	+	O	O[b]
*Blair Graving Dock	+	O	O	+	O
Hylebos WW #1	+	O	+	+	-
Hylebos WW #2	+	O	-	-	-

+ Positive - Negative O Neutral ? Information Needed

[a] Site preparation costs divided by cubic yard capacity of the site.
[b] Relocation of existing marina in inner slip required.
* Further evaluation recommended at this time.

Of the upland sites, Port of Tacoma "D" and the Puyallup River/railroad sites are the most worthy of further evaluation. Their capacities are large, the sites are within pumping distance from a variety of Commmencement Bay dredging sites, and the sites are sufficiently large to permit onsite treatment facilities to be constructed. Because of the existence of the wetland meadow on Puyallup River/railroad site, environmental impacts are rated negative (high impact) in relation to the other sites being evaluated; however, a more detailed examination of environmental effects is warranted. The Port of Tacoma "E" is considered a good candidate due to its location relative to much of the harbor area, but does not have capacity below +20 feet MLLW. The proposal for wetland restoration at the Puyallup mitigation site makes future use unlikely. Although it is not eliminated from future consideration, the site is not recommended for detailed evaluation unless a specific need can be identified. Hylebos Creek Nos. 1 and 2 have a good preparation cost to capacity ratio; however, use of these sites would displace ongoing agricultural activity. In addition, the sites' availability is unknown and its mixed ownership would probably require the site be acquired rather than be made available.

There are generic problems with nearshore disposal sites with regard to containment of contaminated sediments. Nevertheless, as further information is developed, including sediment criteria, techniques for placing and retaining contaminants in nearshore areas may be developed. Of the sites identified and evaluated in Commencement Bay, three are not recommended for further evaluation: Middle Waterway and Hylebos Waterway Nos. 1 and 2. Middle Waterway might be useful for partial fill using contaminated sediments, but it might be more useful dredged out and its navigational capability restored. The outer area is still used; relocation of adjacent landowners and users to other portions of the harbor could be expensive and difficult. Benefits do not appear to warrant the effort. The two Hylebos Waterway sites are probably available, but the cost of one is high in comparison to capacity, and both sites are wetlands with high resource value to Commencement Bay. Further evaluation at this stage does not seem warranted.

Of the remaining three sites, the Blair graving dock has relatively limited capacity; however, its preparation costs are also quite low. The site is more suitable for a one-time disposal and should be considered for such if the opportunity presents itself. The Blair Waterway slips are intended to be filled and developed in the future. They represent a large capacity and preparation costs are reasonable. They are located centrally on the waterfront and would be able to accept sediments from anywhere in Commencement Bay. Environmental impacts are relatively moderate; although mitigation might be required. The largest drawback to the slips is the existing marina in the inner slip that would need to be relocated. Likewise, Milwaukee Waterway presents an opportunity as the port intends to fill the waterway to accommodate Sea-Land and to develop their own container terminal capacity. Milwaukee Waterway has large capacity, is not presently being extensively used for navigation, and has no adjacent users that would have to be relocated. Further evaluation of these three nearshore sites is recommended.

Selection of a particular disposal site requires not only consideration of the factors mentioned above but also acknowledgement of the dredge used and the treatment to be applied following disposal. The best approach in dealing with contaminated sediments may involve a "mixed" approach, especially where there is a limited disposal resource and a variable level of contamination or various classes of contaminants. For instance, sediments that contain high concentrations of heavy metals but are low in organic contaminants can be safely and relatively inexpensively disposed of in capped open-water sites. Sediment that contains high organic concentrations should go to upland disposal sites with their relatively high degree of control and monitoring potential. Most sediments, of course, will fall somewhere in the middle ground and the identification of criteria that are to be met becomes a most important task. If levels of contaminants and criteria specific to those levels can be developed, a more flexible approach may be possible.

One useful approach is selective dredging and disposal. Since treatment costs are very expensive, it would be prudent to treat only those volumes of sediment that meet or exceed the levels that trigger the need for treatment. Further, segregation of the types and levels of contaminated sediments would allow decisionmakers to establish and match criteria specific to the types and amounts of contamination present in each sediment class. And finally, selective dredging and disposal allows maximization of a limited disposal capacity. If there is only capacity for 250,000 c.y. of highly contaminated material, it is inefficient and expensive to fill that site with 25,000 c.y. of highly contaminated sediments mixed with 225,000 c.y. of relatively cleaner material. However, in order to accomplish this, sediment characterization must be done to finer levels than is typically done for most dredging projects. At the same time, this characterization and subsequent segregation must bear in mind the precision of the dredging equipment employed (table 6-1). Having developed suitable criteria, horizontal and vertical sediment characterization can be done to levels that dredging equipment can selectively remove.

Very contaminated sediments should be processed at a treatment facility to remove the cleaner fraction of the sediments, typically the coarser material. This coarse material, often comprising the bulk of the total sediment volume, can then be reused as capping material, open-water disposed, or used as upland fill. The remaining fines can be settled out by a number of techniques and this reduced volume treated or placed in an appropriate holding facility. This option requires hydraulic dredging and possible treatment of effluent. The cost of segregation and rehandling may be compensated for by the reduced cost associated with treating and confining less contaminated sediment.

Another very useful approach is to realize that the costs associated with even the simpler dredging, disposal, and treatment methods are substantial, and when viewed from the perspective of an individual, a small industry, and even a single agency, can be staggering. It is possible that a single, comprehensive disposal site and treatment facility could be established that would be used by those with dredging requirements. The site(s) would be managed by a single entity and would be designed to meet criteria that had been established by a regional or national management plan. Conceptually, the high initial cost for acquiring and developing the disposal site and any associated treatment facilities could be spread between the dredgers and prorated at an unit cost per each cubic yard disposed. This solution would amortize the expense of initial construction over time as well as spreading that cost among users; and it would likely result in less land being impacted and therefore fewer disruptions in land use. Development of such a management plan and/or disposal facility with a managing entity would be a complex and difficult task. For large volumes of contaminated material, such as occurs in Commencement Bay, it may be the only practicable solution.

6.07 Information Needs and Recommended Study. Many of the methods and techniques addressed in this report merit further study, research, and experience in terms of their application to, and relative contribution in, handling of contaminated sediments. A few of the more noteworthy and priority items are identified below.

As pointed out by Thibodeaux (1984, appendix 2a), there can be a big difference between contaminant mobility as predicted by partitioning coefficients and contaminant mobility as seen in the field. *In situ* measurement of contaminants in interstitial waters would verify partitioning predictions. Better quantitative predicting of mobility can be obtained by conducting pilot scale laboratory tests to develop empirical relationships of contaminant mobility under various disposal conditions in combination with the use of mathematical models to predict this mobility. Tests to measure long-term contaminant mobility for the three disposal methods and resulting conditions and developing first stage modeling of mobility should be considered for the near future.

Additional experience and prototype work is needed for several aspects of aquatic disposal of contaminated sediments. Capping of contaminated sediments should be demonstrated using equipment, sediments, and material available in Puget Sound. Experience in placing underwater clay liners is needed. The vertical diffuser should be demonstrated in the United States.

Loss of volatile contaminants through degasser systems on hydraulic dredges should be investigated. Potential loss should be estimated by obtaining field information on the volume of gas in the sediments in situ. Actual loss should be studied by monitoring of degasser discharges.

Additional planning will be needed before the list of potential disposal sites can be pared down to those that are probable for designation. The generic information needs identified in chapter 3 for each type of disposal site should be pursued as part of ongoing planning in Commencement Bay.

The availability of special-purpose dredges could be a major consideration in their use in Commencement Bay. Due to the advantages that these plants offer, specific determinations of their availability are warranted at this stage of planning.

The common theme of dredging, disposal, and treatment discussions above is the identification of pertinent decisionmaking criteria. These should define testing methods and interpretation of test results to determine when certain dredging and disposal options are appropriate and required. Closely associated with the interpretation of test results is the need for better information on the long-term effects of contaminant release to the receiving environment. Development of criteria represents the central link between available disposal sites, the extent and types of sediment contamination, and the navigation and Superfund needs to move that sediment. The criteria will allow assembly of the components of a dredging job: type of dredge, disposal site, and treatment levels, and are at the core of a management plan for Commencement Bay. Therefore, development of decisionmaking criteria should receive primary attention in any future efforts.

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APPENDIX 1

A SOLUBILITY AND MOBILITY CLASSIFICATION OF ORGANIC CHEMICALS IDENTIFIED IN COMMENCEMENT BAY SEDIMENTS

DEPARTMENT OF DEFENSE

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
PO BOX 631
VICKSBURG, MISSISSIPPI 39180

October 26, 1983

REPLY TO
ATTENTION OF
Environmental Laboratory

Dr. Keith Phillips
U. S. Army Engineer District,
Seattle
NPSEN-PL-ER
P. O. Box C-3755
Seattle, Washington 98124

Dear Dr. ~~Phillips~~: Keith

Attached is the classification of Commencement Bay organic chemicals by solubility which you requested under the Dredging Operations Technical Support (DOTS) Program. In addition to the requested classification, the Environmental Laboratory staff is preparing information on the bioavailability and maximum bioaccumulation potential of these chemicals from Commencement Bay sediment. This information will be provided within three weeks.

If there are any questions concerning the attached or upcoming information, please contact Mr. Victor McFarland at (601) 634-3721 or FTS 542-3721. Thank you for the opportunity to provide assistance under the DOTS Program.

Sincerely,

Charles C. Calhoun, Jr.
Manager, Environmental
Effects of Dredging Programs

Attachment

A Solubility and Mobility Classification of Organic Chemicals Identified in Commencement Bay Sediments

Introduction

In this report fifty-six of the organic chemical contaminants most frequently identified in Commencement Bay sediments (Johnson et al., 1983) have been classified according to their solubilities in water and their relative mobilities when bound to soil or sediment. This classification identifies chemicals which may be expected to behave similarly in terms of water solubility and cohesiveness with particulate matter under similar physical conditions.

The water solubility (S) classes are based on the behavior of the chemicals in pure water at 25°C. Since organic chemicals associate primarily with the organic carbon fraction of soils and sediments, their mobilities are based upon soil or sediment organic carbon/water partition coefficients (Koc). Both S and Koc are linearly correlated with octanol/water partition coefficients (Kow) which may be obtained from the literature or calculated using molecular structure techniques. Many of the values of S and Koc listed in this report are derived from Kow, and the remainder are taken from empirical determinations in the literature.

Determinations of S using Kow were by the equation of Yalkowsky, et al., (1983), which corrects for the effect of melting point on the water solubility of isomers. An example is the difference in the classifications given to the isomers anthracene and phenanthrene which fall in different solubility classes although they are similar in mobility.

Mobility classifications follow the scheme of Swann, et al., (1983), and calculations of Koc were made using the equation of Karickhoff (1981).

The procedure for inclusion of data is as follows:

Water Solubility (S)

1. If several experimentally obtained values were reported in the literature, outliers were excluded and the mean of remaining values was used.

2. If values reported in source works were identified as "estimated" they were not used.

3. If single values were found for a given chemical, the single value was used if it appeared consistent with estimation results.

4. If no values could be found for S at 25°C, but were found at other temperatures the values were extrapolated to 25°C.

5. If no values of S could be found they were estimated using Kow and melting point; melting points below 25°C were calculated as being 25°C.

Octanol/Water Partition Coefficient (Kow)

1. Measured values of Kow were treated similarly to measured values of S (means of several reported observations, outliers excluded).

2. If measured values of Kow were not found, the structure of the chemical was established and Kow was calculated by the fragment constant methods of Hansch and Leo (1979).

Mobility (Koc)

1. Reported values of Koc were treated similarly to reported values of S and Kow. Experimental values were used preferentially, but if not available Koc was estimated (Karickhoff, 1981).

Table No. 1

Factors Relevant to Long-Term Contaminant Mobility in Soil/Sediment Environments

1. Chemical Species
   - molecular weight and chemical structure
   - solubility in water and vapor pressure
   - diffusivity in water and in pore gas
   - partition coefficients and Henry's constant

2. Solvents (pore water and pore gas)
   - molecular weight of water and gas
   - concentration and partial pressure of other species

3. Soil/Sediment Matrix
   - porosity (micro, macro)
   - grain size (average and standard deviation)
   - permeability (water and gas)
   - organic fraction and ion-exchange capacity
   - water content (for soil)
   - tortousity
   - level and depth of bioturbation

4. Fluid Properties
   - temperature, pressure and phase (G, L, S)
   - water flow rate and direction
   - gas flow rate and direction

5. Total Contaminant Concentration Level
   - low; $<$ 50,000 ppm (wt)
   - high $\geq$ 50,000 ppm (wt)

6. Geometric Factors
   - length of diffusion and convection pathways
   - cover layer depth
   - disposal cell dimensions

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Table 1

Relative Water Solubility Classification for Organic Chemicals Identified in Commencement Bay Sediments

Rank	Range, mg ℓ^{-1}	Solubility Class
1	1,000 - 10,000	very high
2	100 - 1000	high
3	10 - 100	medium
4	0.1 - 10	low
5	0.01 - 0.1	slight
6	0.001 - 0.01	very slight
7	<0.001	practically insoluble

Table 2

Classification of Chemical Mobility in Soil*

Rank	Approximate K_{oc}	Mobility Class
1	0 - 50	very high
2	50 - 150	high
3	150 - 500	medium
4	500 - 2,000	low
5	2,000 - 5,000	slight
6	>5,000	immobile

* Adapted from: Swann, R. L., et al., in: Residue Reviews, Vol. 85, Springer-Verlag New York Inc., 1983.

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Table 3

Classification by Water Solubility and Soil Mobility of Some Organic Chemicals Identified in Commencement Bay Sediments

		Solubility	Mobility
I.	**Volatile**		
1.	chloroethane	(1)	(1)
2.	1, 1-dichlorethane	(1)	(1)
3.	1, 1-dichloroethylene	(1)	(1)
4.	1, 2-dichloroethane	(1)	(2)
5.	trichloromethane (chloroform)	(1)	(2)
6.	1, 1, 1-trichloroethane	(1)	(2)
7.	benzene	(1)	(2)
8.	bromoform	(1)	(2)
9.	carbon tetrachloride	(1)	(3)
10	1, 1, 2, 2-tetrachloroethane	(1)	(3)
11	1, 2, (trans) dichloroethylene	(2)	(1)
12.	toluene	(2)	(3)
13.	tetrachloroethylene	(2)	(3)
II.	**Base/Neutral**		
1.	nitrobenzene	(1)	(1)
2.	dimethyl phthalate	(2)	(3)
3.	1, 2-dichlorobenzene	(2)	(4)
4.	1, 3-dichlorobenzene	(2)	(4)
5.	1, 4-dichlorobenzene	(3)	(4)
6.	naphthalene	(3)	(4)
7.	2-chloronaphthalene	(3)	(5)
8.	diethyl phthalate	(3)	(6)
9.	bis (2-ethylhexyl) phthalate	(4)	*
10.	di-n-octyl phthalate	(4)	*
11.	hexachlorobutadiene	(4)	(4)
12.	fluorene	(4)	(5)
13.	acenaphthylene	(4)	(5)
14.	acenaphthene	(4)	(5)

(Continued)

* Mobility not estimated

Table 3 (Concluded)

II. Base/Neutral	Solubility	Mobility
15. hexachloroethane	(4)	(6)
16. phenanthrene	(4)	(6)
17. fluoranthene	(4)	(6)
18. butylbenzyl phthalate	(4)	(6)
19. pyrene	(4)	(6)
20. di-n-butyl phthalate	(4)	(6)
21. benzo (a) anthracene	(4)	(6)
22. ideno (1, 2, 3-cd) pyrene	(5)	(6)
23. anthracene	(5)	(6)
24. chrysene	(6)	(6)
25. hexachlorobenzene	(6)	(6)
26. benzo (b) fluoranthene	(6)	(6)
27. benzo (a) pyrene	(6)	(6)
28. benzo (k) fluoranthene	(6)	(6)
29. benzo (g, h, i) perylene	(7)	(6)
III. Acid Extractable		
1. phenol	(1)	(1)
2. p-chloro-m-cresol	(1)	(1)
3. 4-nitrophenol	(2)	(1)
4. 2-chlorophenol	(2)	(2)
5. 2, 4, 6-trichlorophenol	(3)	(5)
6. pentachlorophenol	(4)	(6)
IV. Pesticides and PCB's		
1. aldrin	(2)	(3)
2. lindane (γ-BHC)	(3)	(5)
3. 4, 4' - DDD	(4)	(6)
4. PCB - 1242, 1016	(4)	(6)
5. 4, 4' - DDE	(5)	(6)
6. PCB - 1248	(5)	(6)
7. PCB - 1260	(5)	(6)
8. 4, 4' - DDT	(6)	(6)

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APPENDIX 2

REVIEWS OF LONG-TERM CONTAMINANT MOBILITY FOR VARIOUS DISPOSAL OPTIONS IN COMMENCEMENT BAY

APPENDIX 2

TABLE OF CONTENTS

a. Review by Dr. Louis J. Thibodeaux, University of Arkansas

b. Review by Dr. Paul V. Roberts, Stanford University

Louis J. Thibodeaux, Ph.D.
PROFESSOR
Department of Chemical Engineering

University of Arkansas, College of Engineering • Fayetteville, Arkansas 72701
Engineering Building, West Dickson Street, Room 331 • (501) 575-4951 • Home (501) 521-3837

January 4, 1984

Dr. Keith Phillips
U.S. Army Engineer District, Seattle
NPSEN-PL-ER
P.O. Box C-3755
Seattle, Washington 98124

Dear Keith:

Enclosed is the letter report that provides my opinion on the long-term mobility of sediment-related contaminants under various disposal conditions in Commencement Bay. If you have any questions or would like more details on some aspects please give me a call.

Thanks for the opportunity to be a part of this effort; it is a very interesting problem.

Sincerely,

Louis J. Thibodeaux
Professor

krd

Enclosure

--LETTER REPORT--

Expert Opinion on Disposal Options for Contaminated Dredge Material from Commencement Bay, Tacoma, Washington

Louis J. Thibodeaux, P.E.
January 3, 1984

The Seattle District, U.S. Army Corps of Engineers, under agreement with the State of Washington Department of Ecology, is evaluating alternative dredging methods, disposal sites and site control (treatment) practices for contaminated sediment derived from the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Disposal options available in Commencement Bay include: subaquatic disposal (with or without capping), partially aquatic disposal (intertidal/subtidal fill) and upland disposal. There are insufficient empirical data on the Commencement Bay sediments to quantitatively distinguish differences between these disposal options in terms of long-term contaminant mobility. In order to distinguish contaminant containment efficiencies of these disposal options and recommend specific disposal sites and treatment practices, a review of Commencement Bay sediment and contaminant data with respect to contaminant mobility is needed.

There appears to be some confusion about the term mobility. Calhoun (1983), adopting from Swann, et. al., uses the term in a thermodynamic sense. He classifies the organic compounds by mobility class when in fact his classification reflects the degree to which the organic species partition onto the soil sediment organic fraction during a reversible equilibrium sorption environment. The proper coefficient should be the desorption coefficient measured under sea-water salt concentration conditions. Even this coefficient is inturn related to mobility in a complex manner.

Mobility implies a rate process and a time, either implicit or explicit, need be quantified. Mobility or transport is a function of the chemical species, the solvent (water), the type of soil/sediment matrix, the physical state of the system, chemical concentration levels and certain geometric factors. These seven factors are inturn subdivided into quantifiable or specific values as shown in Table 1. It is apparent from this list that the partition coefficient addresses only one small facet of the mobility question.

There are several physical/chemical/biological processes that can and do result in contaminant mobility (or transport). When considering these mobility aspects it is assumed that the issue is the question of contaminants within a sediment/water environment. Contaminants can be mobilized and move between two points in space by the following mechanisms:

1. diffusion of dissolved species down a concentration gradient and through the sediment-water interface,
2. convective and dispersion of dissolved species (and fines) due to the water flow through the sediment,
3. bioturbation in the top layer of the sediment
4. scour and suspension of surface sediment particles due to bottom water currents,
5. gas generation and ebullition within and through the sediment/water interface.

All of these mechanisms can be active in some of the disposal options while only one or two may be active in others. The point is that there will always be some active transport mechanisms operative in all disposal options and that none of the options will provide a complete isolation of the contaminants from the Commencement Bay ecosystem. It is likely that one or more of the options will provide sufficient containment and acceptable levels of contaminant mobility.

Application

Table 1 provides a ranking in order-of-magnitude steps of solubilities of the organic chemicals considered in this report. The ranks correspond to the column headed "solubility" in Table 3. The verbal descriptors are chosen arbitrarily, indicate only relative solubilities, and are specific to this report.

Table 2 ranks the mobility of chemicals in soils and sediments according to their partitioning behavior between water and soil or sediment organic carbon. The numerical ranks correspond to the column headed "mobility" in Table 3.

The arrangement of Table 3 is by analytical preparation type, i.e., Volatiles, Base/Neutrals, etc., with chemicals ranked within each type by decreasing solubility and mobility. Chemicals which are ranked similarly in each type may be considered to behave similarly in their solubility and mobility properties.

These data are provided with the reservation that pure water solubilities of hydrophobic organic chemicals do not accurately represent their behavior in aqueous environmental systems. Mobility calculations consider some of the factors in addition to solubility influencing movement of chemicals in the environment. Therefore, mobility calculations provide additional useful information for classifying chemicals in terms of potential environmental concern.

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Mobility of contaminants can be assessed in two ways. Field techniques usually involve contaminant concentrations measurements and phase (i.e., water or sediment) movement measurements (Pavlou, et. al., 1982). The field techniques available for addressing contaminant mobility have some model concepts, either implicity or explicitly associated with the methodology or instrumentation. The other means of addressing questions of contaminant mobility is by the application of models. These models are primarily mathematical constructs involving the factors listed in Table 1. These constructs can be elaborate computerized assemblages such as the EXAMS (Exposure Analysis Modeling System) model or they can be simple vignette models which focus on isolated events that account for a few dominant transport/fate mechanisms. Models usually reflect much laboratory simulation work and ocassionally receive complete field testing and verification. However, they are being used extensively because of low cost and relatively high confidence interval.

The field work that has been performed in Commencement Bay is inadequate to quantify the rate of mobility of contaminants from the "hot spots" around the various waterways into the near regions of the Bay and the farther regions of the Sound. The use of the term mobility here refers to the mass of selected chemical species and/or all components leaving the waterways per day. The field work that has been reported on is water currents (both surface and subsurface) and directions in the Bay and in the individual waterways and chemical concentrations in the sediment and in the water. These field measurements reflect the fact that contaminants have been mobilized from the waterways and that the Bay currents are present to move the contaminants into the Bay and further afield to the Sound, but the data does not allow flux rates of individual species of total mass flux rate to be quantified. However, the available field data does provide a basis to commence the use of models that will address contaminant

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mobility questions.

It seems to me that the quantification of chemical release rates is one of the preferred method of evaluating disposal options. The release rates associated with the base case (i.e., the waterways contaminant situation as it exist now, before clean-up) need be made in order to assess the effectiveness of any proposed clean-up and disposal plan. Otherwise the relative merits of the variously proposed plans will be done on a purely qualitative basis. Since the field work necessary to completely quantify rates of mobility for the base case and proposed disposal options is incomplete and obtaining completely satisfactory data will be exceedingly costly and time consuming, it seems to me that fate/transport models need be utilized at this time to answer questions of clean-up/disposal options and relative degree of isolating the contaminants from the Bay ecosystem.

The key question, as I see it, is which disposal options will isolate the contaminants from the environment to such a degree that the residual chemical release rates will be significantly lower than the present release rates as to not significantly effect the biota in the Bay to a deleterious extent. At present there are data gaps, insufficient data analysis and an insufficient modeling, effort and analysis, to quantitatively distinguish between disposal options in terms of mobility. In order to distinguish contaminant efficiences of the proposed and other disposal options the following preliminary design scenario, data acquisition and fate/transport modeling tasks should be undertaken:

A. Preliminary Design Scenario Tasks

1. decide on likely specific location for disposal options (i.e., where in waterway, in Bay, upland, etc.)

2. decide on disposal configuration and manner at each location (i.e., water depth, cover thickness, lateral extent, etc.),
3. estimate the mass (or volume) of sediment involved in clean-up,
4. decide on if and how the various contaminated sediments will be combined into highly, medium or slightly contaminated portions for disposal, and
5. choose selected individual chemical species that are characteristic of the various classes of organic compounds and metals for specific modeling studies.

B. Data Aquisition Tasks

1. review the sediment contaminant data and choose reasonable concentration levels for the selected chemicals to be modeled,
2. review the factors presented in Table 1, paying particular attention to those factors with little or no (disposal) site specific information, and
3. review the model demands (next section) for particular data requirements of the algorithms.

C. Fate/Transport Modeling Tasks

1. choose an appropriate fate/transport model such as EXAMS, that contains conical element options that will correspond to the various disposal options
2. if no such model is available then effort need be devoted to assemble vignette models for each disposal option, and
3. perform model simulations that deliver (either directly or indirectly) the rate (g/h) of emission of individual chemicals associated with the various disposal options. The appropriate emission rates are those that relate the amoung leaving the contaminated sediment disposal sites and

re-entering the Bay. Ancillary outputs include contaminant life-time or residence time within the disposal cells, fraction converted by reaction (i.e., hydrolysis, chemical, biological), the fraction irreversibly sorbed and the fraction transported out.

The disposal options that should be considered in the modeling effort are as follows:

1. leave contaminated sediment in-place (serves as the "base case"),
2. sub-aquatic contaminated sediment disposal at a deep-water site without capping,
3. sub-aquatic disposal at deep-water site with caping,
4. sub-aquatic in a waterway (Rotterdam-Putten Plan) with clay liners (Kleinbloesem and van der Weijde, 1983),
5. partial aquatic (nearshore fill above high tide),
6. upland, and
7. combination of the above considering high, medium and low sediment contaminant levels.

Figures 1 through 6 illustrate the basic concept of each disposal option and indicate transport direction (arrows) of mobility mechanisms.

Mobility mechanisms that need be considered in the various modeling task are indicated on the illustration of each disposal option. Figure 1 illustrates the transport pathways for mobile contaminants as they presently exist in the waterway. The transport processes are: scour of fines from the silt surface, gas ebullition, bioturbation, diffusion and convection. Groundwater infiltration from underneath originates in the fill zones that separate the waterways.

The Rotterdam-Putten Plan disposal option is illustrated in Figure 2. This option enjoys a fewer number of transport mechanisms. Bottom water currents flowing over a wavy sediment bed can induce pore water currents within the upper layers of the sediment. Due to the dead-end nature of the waterways the currents may be small and this mechanism of convective transport is not illustrated. It is illustrated in the sub-aquatic disposal options figures.

The model studies should have two subelements that reflect the transient or start-up period of the mobility question and the steady-state or quasi steady-state period. For example, in the Rotterdam-Putten Plan option where contaminated sediment is buried in a lined "vault" within the waterway, there will be a period of time that will lapse before quantities of the contaminants will reappear at the sediment-water interface. Once all the sorption sites along the transport pathway are filled then the process enters the steady-state mode and chemical quantities re-entering the waterway assumes the highest values.

The deep-water disposal options are illustrated in Figures 3 and 4. The without capping option has essentially the same transport mechanisms as the "base case" except that the magnitude of the fluxes will be different. The sand cap that can be placed upon the deep-water disposed sediment will retard the transport somewhat. Likely gas generation and bioturbation will be reduced significantly.

The partial aquatic disposal option is illustrated in Figure 5. Water convection due to tidal pumping will likely be a dominant and efficient mechanism for extracting contaminants from the contaminated sediment cell. Groundwater and rainwater leachate and diffusion processes will be present. Volatilization will occur from the unsaturated sediment zone, but this fraction will not likely re-enter the waterway. Oxidation processes will be active in the unsaturated zone releasing metals that may otherwise be in a sorbed state.

The upland disposal option is illustrated in Figure 6 and has volatilization and leachate transport mechanisms. Oxidation processes will likely be more

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active than in the partial aquatic disposal option.

All things considered a qualitative evaluation based on the number of active transport mechanisms and the control and effectiveness of the disposal operation and containment would suggest that the Rotterdam-Putten Plan is the preferred from a mobility standpoint. The next to best option is the deep-water with capping. A reasonable compromise would be to bury the highly contaminated sediment in the waterway and place the remainder in deep water with a cap.

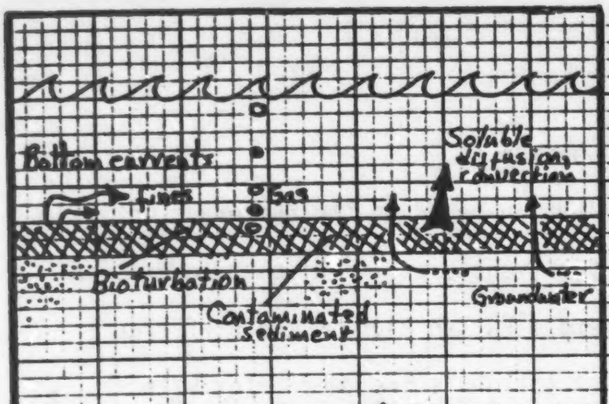


Figure 1. Sediment in Waterway "Base Case"

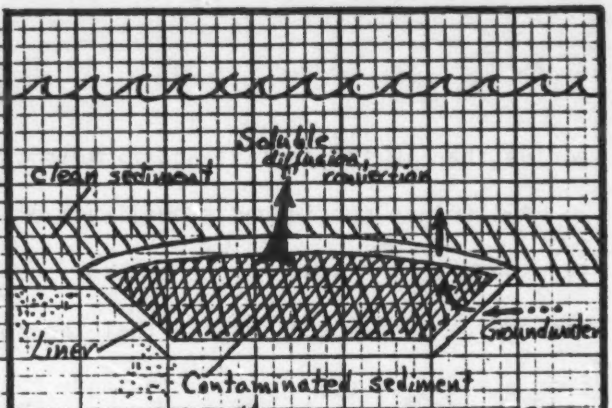


Figure 2. Rotterdam-Putten Plan in Waterway Disposal

Figure 3. Subaquatic, Deep-water Disposal w/o Capping

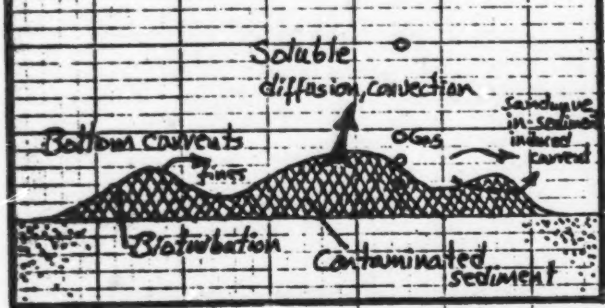

Soluble diffusion, convection
Bottom currents
Fines
Gas
Sandwave in-sediment induced current
Bioturbation
Contaminated sediment

Figure 4. Subaquatic, Deep-water Disposal with Capping

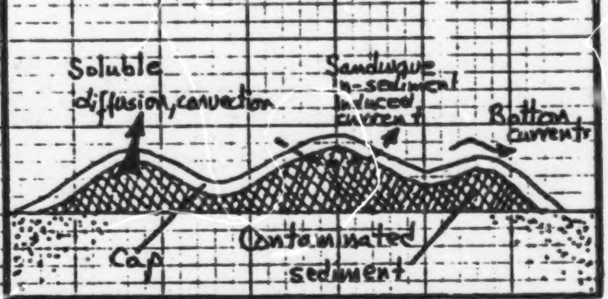
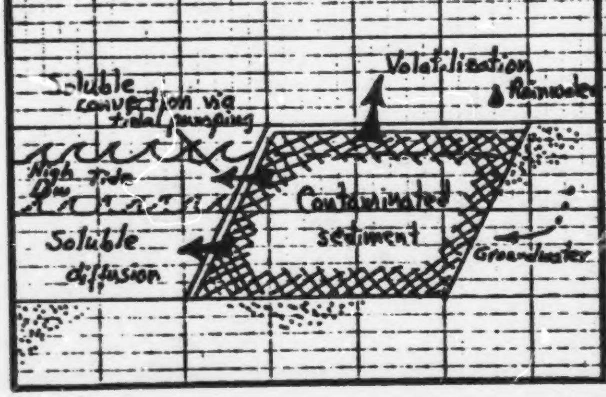

Soluble diffusion, convection
Sandwave in-sediment induced current
Bottom currents
Cap
Contaminated sediment

Figure 5. Partial Aquatic Disposal



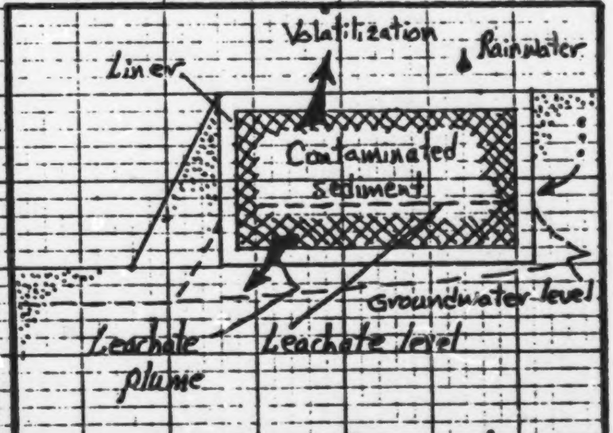


Figure 6. Upland Disposal

B13

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Kleinbloesem, W. C. H., and R. w. von der Weijde, A Special Way of Dredging and Disposing of Heavily Polluted Silt in Rotterdam, Paper M2, World Dredging Congress, Mandarin Singapore, Aug. 19-22, 1983.

B17

Environmental Engineering & Science
DEPARTMENT OF CIVIL ENGINEERING
TERMAN ENGINEERING CENTER
STANFORD UNIVERSITY

PAUL V. ROBERTS
ssociate Professor of Environmental Engineering

STANFORD, CALIFORNIA 94305
(415) 497-1073

31 December 1983

Mr. Keith Phillips
Seattle District
Corps of Engineers
P.O. Box C-3755
Seattle, Washington 98124

Dear Mr. Phillips:

At your request, I have reviewed the available information on alternatives for disposing of contaminated sediments from Commemcement Bay. This work was carried out under P.O. DACA 67-84-M-0947. This letter report represents the result of my evaluation effort under that agreement.

Of the several options proposed, capped deep-water disposal appears to offer the best assurance of isolating the contaminated sediments in such a way that human populations will not be exposed to the contaminants in concentrated form. However the technology of controlled disposal and capping of the deposit in deep water is largely unproven. Extreme care and a substantial measure of technological improvement will be necessary to prevent dispersal of the contaminants throughout Commencement Bay and Puget Sound.

Both of the other two groups of alternatives, upland disposal and near-shore disposal, pose more immediate environmental and health risks than does deep-water disposal. Given the hydrologic conditions in the Tacoma region, it seems inexorable that serious pollution of groundwater and contiguous waterways would result from disposal landfills at upland sites in the Port of Tacoma vicinity. On the other hand, if near-shore disposal were chosen, there would be continual exposure of the contaminated sediments to large volumes of water as a result of tidal fluctuations, with direct impact on the shallow-water portion of Commencement Bay.

The key to the successful isolation of contaminated sediments in deep water is the ability to deposit sediments and cover material directly onto the bottom in a precise manner and with an exit velocity sufficiently low to prevent escape of fines as turbidity. Such a technique was described and recommended by Mr. Norman Francinques at the 14 December meeting on sediment mobility issues. The method entails depositing the sediment through a specially designed diffuser, which achieves horizontal egress of the sediments at low velocity, 0.3 to 0.4 m/s. This technique has been applied effectively for disposing of contaminated sediments in Rotterdam Harbor, as detailed in a paper[1] distributed by Mr. Francinques at the 14 December meeting. However, a major difference between the Rotterdam application and the proposed Commencement Bay application must be recognized: at Rotterdam the water depth was approximately 10m, whereas the deepwater disposal sites in Commemcement Bay lie at depths of 30 to 150 m. Moreover, in the Rotterdam operation, the cap material was not deposited with the diffuser described above, but rather dumped beside the previously deposited sediments and drawn over the deposit by means of a bottom leveler. This latter method seems poorly suited for use at the depths characteristic of Commencement Bay. The reason given for not using the diffuser to place the cap material in Rotterdam Harbor is that the clay cap material was too lumpy to be pumped. Clearly, the amenability to pumping should be a a major criterion in choosing the cap material. From the viewpoint of scour resistance as well as pumpability, a well-sorted sand might be preferable to clay as capping material.

To assess deepwater disposal options, more complete information on current velocities is essential. Strong near-bottom currents would disperse fines during disposal of the contaminated sediments, and would resuspend uncapped sediments or deplete the cap by scouring after disposal. The available information on current velocities is inadequate for evaluation of deepwater disposal alternatives. The most complete study[2] to date concludes that "it is possible that near-bottom currents might be large enough to resuspend bottom sediments". The same study indicates that the dominant flow is along the bay shores, particularly the south shore, where near-bottom current velocities on the order of 20 cm/s were observed. Moreover, it was found that deep water transits the bay in about a day, indicating that soluble contaminants would be rapidly disseminated if exposed.

The question of transport of fine sediments during disposal, or resuspension of exposed sediments, is critical to the efficacy of deepwater disposal as a containment strategy. Although the sediments are relatively coarse-grained, consisting predominantly of sand, there are substantial amounts of fines. Silt fractions range from 1 to 50 percent, and clay fractions from 4 to 45 percent.[3] Positive correlations between fines content and ignition loss point toward the fine fractions having higher organic contents than the sand, as expected. There are no data available on the distributions of hazardous contaminants according to particle size, but it can be assumed that the contaminants associated with particulates are highly concentrated in the fine fractions. Hence, dissemination of fine particulates during disposal would cause disproportionate dissemination of the contaminants of concern. More data are needed on the contaminant concentrations of the silt and clay fractions.

The fraction of organic matter in the sediments is crucially important, because of the known propensity of hydrophobic organic contaminants to partition into organic phases. As a first approximation, it can be assumed that sorption onto sediments from the aqueous phase obeys a linear equilirium relationship, and that the sorption coefficient of a sediment is proportional to its organic content,[4] as measured by organic carbon. Further, the sorption coefficient is proportional to the hydrophobicity of the organic contaminants, as measured by their octanol-water partition coefficients. The organic content of Port of Tacoma waterway sediments is virtually unknown; only a few crude measurements, of volatile solids content, have been made. Dames and Moore (letter of 2 September 1970) contend that the organic content of Blair Waterway sediments is "considerably less than one percent." Several measurements of volatile solids by Laucks Testing Laboratories indicate organic contents of 0.8 to 2.6 percent in Blair, 0.8 to 4.3 in Sitcum, and 1.9 to 7.0 percent in Hylebos waterway. Because the organic fraction typically is comprised of 40 to 50 percent carbon, we can surmise that the organic carbon content of Port of Tacoma waterway sediments is in the range of 0.5 to 3 percent, with values for the more heavily contaminated sediments tending to be toward the upper end of the range. Accordingly, sediment-water partition coefficients may be expected to range from approximately 1:1 for the least hydrophobic contaminants identified (e.g. chloroform and trichloroethylene) to 10,000:1 for the most strongly hydrophobic contaminants (e.g. DDT, polynuclear aromatic hydrocarbons, and polychlorinated biphenyl isomers).

It must be recognized that the bulk of the organic matter in the sediments has yet to be identified. For example, in the most highly contaminated sediments of Hylebos Waterway, the organic content is on the order of 20 to 70 g/kg, but specific organic analysis has identified a total of only 0.03 g/kg. Of course, this comparison is not strictly permissible, because the analyses were performed on different sediment samples, but the fact remains that by far the greater portion of organic matter is unaccounted for, certainly more than 99 percent. What is the nature and provenance of the uncharacterized portion of the sediment organic matter? Can the bulk of the organic matter be assumed to be innocuous, simply because its constituents are not amenable to analysis by a given priority pollutant protocol? It is likely that some of the uncharacterized organic matter is of natural origin, but the elevated organic content of contaminated sediments compared to background levels indicates that most of the organic content is anthropogenic. A large portion is likely to consist of fuel oil fractions and their decomposition products. Further work is needed to characterize the unidentified organic matter, but complete characterization is not attainable with presently available analytical techniques.

There is some possibility of loss of volatile organic constituents to the atmosphere during sediment dredging, transport, and disposal. This danger is greatest under conditions of intimate air-water contact and high energy dissipation. In this regard, the critical point is the extent of gas evolution, especially during dredging. The dimensionless air:water partition coefficients are on the order of 0.01 to unity for the organic compounds specifically identified in the Tetra Tech report. Of these compounds, the most volatile is trichloroethylene, with an air:water partition coefficient of 0.5; losses as great as 10 to 20 percent might be expected if substantial gas evolution occurs (i.e., equal volumes of gas and sediment).It might be prudent as an occupational safety measure to collect the evolved gas and pass it through an adsorber filled with activated carbon or equivalent gas-cleaning agent.

To prevent diffusive escape of contaminants after disposal, the thickness of both the sediments and the cap should be as great as feasible. This argues for minimizing the surface area of the disposal site by disposing into an underwater pit. Seemingly, there is a natural site with these characteristics in Commencement Bay. Along the northeast shore near the present barge storage area is a natural depression that may be suitable for disposing of contaminated sediments. Disposing into such a natural depression would enhance containment in several ways. The horizontal containment on all sides would hinder dispersal of fines during disposal, and would facilitate placing the cap. The relatively great depth of sediment deposit attainable in this situation, approximately 30m, would assure a low surface-to-volume ratio that would minimize diffusive transport of contaminants into the water column and hence assure long-term containment. The low surface-to-volume ratio also would reduce the amount of capping material required to achieve a given cap thickness. Also, depositing the sediments into a pronounced depression would facilitate subsequent locating of the wastes for monitoring purposes, because bathymetry would provide positive identification. Moreover, that particular site affords the practical advantage of being at lesser depth than the present deepwater disposal site in the middle of Commencement Bay. Nevertheless, the depth of the prospective operation (30 to 60 m) poses a technological challenge. To this reviewer's knowledge, precise, nondispersive placement of sediment and cap at that depth has yet to be demonstrated. The above-mentioned site should be carefully studied with respect to bathymetry, near-bottom current velocities, biological impacts, and potential conflicts with other uses. The availability of suitable, uncontaminated capping material should also be ascertained. The cap thickness should be designed for an average of at least one metre to alleviate the effects of irregularities in deposition, scouring by currents, and bioturbation.

In summary, I believe that capped deepwater disposal is the least objectionable alternative for disposing of contaminated sediments from the Port of Tacoma. If confinement can be achieved by depositing the sediments in a bottom depression followed by capping, relatively secure containment can be assured. Before that alternative is chosen, however, it must be demonstrated at Commencenent Bay that the sediments can be accurately deposited in a confined bottom area without loss of fines, that the deposit can be uniformly capped with clean cover material in sufficient thickness, and that the cap's integrity can be effectively monitored.

Demonstrating the feasibility of the preferred alternative - capped,deepwater disposal - will entail a substantial commitment by the Corps of Engineers. Only a thorough, onsite demonstration under the conditions of the prospective Commencement Bay disposal operation would suffice.

Sincerely,

Paul Robts

Paul V. Roberts,PhD

APPENDIX 3

TREATMENT CALCULATIONS

C1

APPENDIX 3

TREATMENT CALCULATIONS

C1

INTRODUCTION

This appendix provides base calculations and assumptions for many of the costs displayed in Chapter 5.0.

C2

EFFLUENT FLOW RATE

For 24" Dredge Working 10 hrs/day:

$$Q = (19{,}748 \text{ gpm})(60 \text{ min/hr})(10 \text{ hr/day})(1 \times 10^{-6}) = 11.85 \text{ mgd}$$

say 12 mgd

Production Rate for 24" Dredge: 900 yd^3/hr

$$\frac{1{,}000{,}000 \text{ yd}^3}{900 \text{ yd}^3\text{/hr}} = 1{,}111 \text{ hrs}$$

Operating Time Per Day: 10 hrs

$$\frac{1{,}111 \text{ hrs}}{10 \text{ hrs}} = 111 \text{ days}$$

Treatment will be needed 24 hrs/day for a period of 111 days. Say 4 months.

Dredging costs for 24" - pipeline suction = \$1.50/yd^3

For 1,000,000 yd^3 @ \$1.50/yd^3 = \$1,500,000.00

C3

PRIMARY CONTAINMENT AREA

Primary containment area design is discussed in EM 1110-2-5006 (Department of Army, 1980). As a preliminary design, the area is designed based on storage requirements.

Assume:

Volume of Settled Material = 1.7×10^9
Depth of Settled Material = 12 ft
Minimum Ponded Depth = 2 ft

Required Area Based on Storage Area =

$$\frac{1.7 \times 10^9 \text{ L}}{(28.31 \text{ L/ft}^3)(12 \text{ ft})(43{,}560 \text{ ft}^2\text{/acre})} = 115 \text{ acres}$$

C4

POLYMER FEED SYSTEM

Polymer Feed Design:

Assume:

Sediment Volume = 1,000,000 yd^3
Sediment Concentration (In Situ) = 900 g/l
Specific Gravity = 2.68
Dredged Material Slurry Concentration = 150 g/l
Dredge Pipeline Size = 24"
Average Concentration of Settled Material = 400 g/l
Specific Weight of Polymer = 1.1 kg/l
Polymer Feed Concentration = 20 g/l
Required Polymer Dosage = 5 mg/l
Average Influent Flow Rate = 12 mgd of 18.57 cfs

1. Volume of Inflow =

$$(1{,}000{,}000\ yd^3)(900\ g/l)(764.4\ l/yd^3)/(150\ g/l) = 4.6 \times 10^9\ L$$

2. Volume of Settled Material =

$$(4.6 \times 10^9\ L)(150\ g/l)/(400\ g/l) = 1.7 \times 10^9\ L$$

3. Volume to be Treated =

$$4.6 \times 10^9 - 1.7 \times 10^9 = 2.9 \times 10^9\ L$$

4. Volume of Polymer Required, gal =

$$(5\ mg/l)(2.9 \times 10^9\ L)/(1.1\ kg/l)(3.785\ L/gal)10^6\ mg/kg = 3{,}480\ gal$$

5. Pounds of Polymer Required =

$$(3{,}480\ gal)(3.785\ L/gal)(1.1\ \frac{kg}{L})(20{,}205\ lb/kg) = 31{,}950\ lb$$

Concentrated Polymer Flow Rate =

$$(18.57\ cfs)(5\ mg/l)(28.31\ L/ft^3)/(1.1\ g/ml)(1{,}000\ mg/g) = 2.17\ ml/sec = 0.0344\ gpm = 49.6\ gpd$$

Polymer Feed Tank Volume =

$$(49.6\ gpd)(2\ days) = 99.2\ gal$$

Dilution Water Pump Rate =

$$2\ (1.1\ g/ml)(1{,}000\ ml/l)(0.0344\ gpm)/(20\ g/l) = 3.784\ gpm$$

C5

MUD PUMPING

Volumetric Pumping Rate, gpd

(0.5 - 0.03)g/l x 18.57 cfs x 28.31 L/day x 86,400 sec/day / (3.785 L/gal)(88 g/l) = 64,100 gpd or 45 gpm

SECONDARY SETTLING BASIN

Secondary Settling Basin:

Assume:

Primary Effluent Solids Concentration = 500 mg/1
Secondary Effluent Solids Concentration = 30 mg/1
Volume to be Treated = 2.9×10^9 L
Depth of Basin = 6 ft
Average Flow = 18.57 cfs
Depth of Storage = 3 ft
Depth of Ponding = 2 ft

1. Volume of Settled Treated Material:

Mass of Settled Material =

$$(0.5 - 0.03)\text{g/1} \times 2.9 \times 10^9 \text{ L} = 1.36 \times 10^9 \text{ g}$$

Average Concentration of Settled Material =

$$((2 \times 50 \text{ g/1}) + 25 \text{ g/1/ft} \times 3 \text{ ft}) / 2 = 88 \text{ g/1}$$

Volume of Settled Material =

$$1.36 \times 10^9 \text{ g/88 g/1} = 1.55 \times 10^7 \text{ L} = 12.5 \text{ ac-ft}$$

2. Required Area Based on Storage Area =

$$12.5 \text{ ac-ft/3 ft} = 4.2 \text{ acres}$$

3. Required Area Based on Ponding =

$$18.57 \text{ cfs} \times 9{,}000 \text{ sec/(2 ft)(43,560 sq ft/acre)} = 1.9 \text{ acres}$$

FILTRATION DIKE

Filtration Dike Length:

Secondary Effluent Solids Concentration = 30 mg/l

Throughput/sq m = 8×10^4 M^3/M^2

Q = 11.5 mgd = 0.5 M^3/sec

For 6 Months, Q = (11.5 mgd)(365/2) = 2.1×10^9 gal
= 7,946,235 M^3

For a 6' Top Width and a 10' Height With a 2:1 Slope Area =

$$(2)(1/2)(10')(20') + (6')(10') = 260 \text{ SF}$$
$$= 24.2 \text{ M}^2$$

Surface Area/LF = (13.4')(1') = 13.4 SF
= 1.2 M^2

For Each LF, Throughput =

$$(8.4 \times 10^4)(1.2) = 10.5 \times 10^4 \frac{M^3}{2}$$

$$L = 7,946,235 \text{ M}^3/10.5 \times 10^4 \text{ M}^3/\text{LF} + 76'$$

C8

MIXED MEDIA FILTRATION

Mixed Media Filtration:

Hydraulic Load = 5 gpm/SF

Q = 11.5 mgd

$$\text{Surface Area} = \frac{(11.5 \times 10^6 \text{ gpd})/1{,}440 \text{ min}}{5 \text{ gpm/SF}} = 1{,}600 \text{ SF}$$

Provide 8 200-SF Units 20' x 10' Cells

C9

RUNOFF AND LEACHATE FLOW RATES

The Hydrologic Evaluation of Landfill Performance (HELP) model was run to estimate runoff and infiltration through the cap (Shroeder, et al., 1983). It was assumed that all water that infiltrated through the cap would contribute fully to the leachate production. The area used in the calculations was 80 acres.

Results:

Average Annual Leachate Production	5,086,000 gal
Average Flowrate	13,900 gpd
Average Annual Runoff	25,944,000 gal
Average Flowrate	71,080 gpd
Average Annual Rainfall	35.6 inches
Average Annual Runoff	13.3 inches
Average Annual Evaportranspiration	19.9 inches
Average Annual Leachate Production	2.4 inches

C10

ACTIVATED CARBON

Activated Carbon Adsorption:

Q = 11.5 mgd = 19,800 gpm

Hydraulic Load = 5 gpm/SF

Contact Time = 30 min

$SA = (19{,}800 \text{ gpm})(\frac{10}{24})/5 \text{ gpm/SF} = 1{,}650 \text{ SF}$

Use 15 columns, SA = 110 SF/column

D = 12'

Actual Area = $(\quad)(12^2/4) = 113$ SF
$(113)(15) = 1{,}696$ SF

Actual Hydraulic Loading = $(19{,}800)(\frac{8}{24})/1{,}696 = 3.9$ gpm/SF

Bed Depth Required at 30 min Contact Time

$$V = \frac{(19{,}800 \text{ gpm})(30 \text{ min})8}{(7.48 \text{ gpsf})(20)(24)} = 1{,}324 \text{ cf/unit}$$

Bed Depth = 1,324/113 = 11.7'

Supply 40% Expansion Room at Top for Backwashing and 3.0 ft for Freeboard Depth = (0.4)(11.7) + 3.0 + 11.7 = 19.4' (say 20')

Carbon Required = (300 #/mg)(11.5 mgd) = 3,450 #/day

Use 15 - 12' diameter 20' high filters

COSTS FOR PROVIDING PLAIN SEDIMENTATION AT A NEARSHORE DISPOSAL SITE
(30-AC POND)
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Clay Liner 3 Feet Thick	150,000	CY	$18.29	$2,744,000
20 Mil PVC Cap	30	AC	10,000.00	300,000
Earth Cover 2 Feet Thick	112,500	CY	4.00 1/	450,000
Fencing 6 Feet High Chainlink	2,000	LF	6.00	12,000
Landscaping Dry Land Seeding	30	AC	1,000.00	30,000
Weir Structure	1	JOB	LS	12,000
External Dike	1	JOB	LS	925,000
Site Development	1	JOB	LS	50,000
		Subtotal		$4,523,000
		Contingency ± 30%		1,357,000
		TOTAL		$5,880,000

OPERATION AND MAINTENANCE COSTS

	Quantity	Unit	Unit Price	Total Cost
O&M	4	MO	$10,000	$40,000
		Contingency ± 25%		10,000
		TOTAL		$50,000

1/Quotation from Commencement Bay.

C12

COSTS FOR PROVIDING PLAIN SEDIMENTATION AT AN UPLAND DISPOSAL SITE (80-AC POND)

(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Clay Liner 3 Feet Thick	400,000	CY	$16.29	$6,516,000
Leachate Underdrain	50,000	LF	4.00	200,000
Granular Bedding	160,000	CY	5.00	800,000
45 Mil Hypolan Liner	80	AC	35,000.00	2,800,000
Dewatering Drain	50,000	LF	4.00	200,000
Excavation/Stockpile	300,000	CY	0.75	225,000
20 Mil PVC Cap	80	AC	10,000.00	800,000
Earth Cover 2 Feet Thick From Stockpile	300,000	CY	0.75	225,000
Fencing 6-Foot Chainlink	12,000	LF	6.00	72,000
Landscaping Dryland Grass Seeding	80	AC	1,000.00	80,000
Weir Structure	1	JOB	LS	12,000
External Dike	1	JOB	LS	480,000
18-Inch 0 Effluent Pipeline	5,000	LF	20.00	100,000
Site Development	1	JOB	LS	100,000
		Subtotal		$12,610,000
		Contingency ± 25%		3,152,500
		TOTAL		$15,762,500

OPERATION AND MAINTENANCE COSTS

O&M	4	MO	$10,000	$40,000
		Contingency ± 25%		10,000
		TOTAL		$50,000

CHEMICAL CLARIFICATION COSTS IN ADDITION TO PLAIN SEDIMENTATION
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Internal Diking	10,000	CY	$4.00	$40,000
Weir Structure and Discharge Culvert	1	JOB	LS	12,000
Polymer Feed System	1	JOB	LS	60,000
Mud Pumping System	1	JOB	LS	50,000
Operation Facility Portable Building 8' x 12'	1	JOB	LS	9,000
		Subtotal		$171,000
		Contingency ± 25%		43,000
		TOTAL		$214,000

OPERATION AND MAINTENANCE COSTS

Polymer		$65,000
Labor		105,000
Energy		3,000
Maintenance Material		3,000
	Subtotal	$176,000
	Contingency ± 25%	44,000
	TOTAL	$220,000

COSTS FOR PERVIOUS DIKES AT UPLAND AND NEARSHORE DISPOSAL SITES
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Pervious Dike	10,000	CY	$10.00	$100,000
Conventional Dike Replaced	10,000	CY	4.00	(-) 40,000 savings
		Net Cost		$60,000
		Contingency ± 25%		15,000
		TOTAL		$75,000

OPERATION AND MAINTENANCE COSTS

	Quantity	Unit	Unit Price	Total Cost
O&M	4	MO	$1,000	$4,000
		Contingency ± 25%		1,000
		TOTAL		$5,000

COSTS FOR SANDFILL WEIRS AT UPLAND AND NEARSHORE DISPOSAL SITES
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Filter Medium	1	JOB	LS	$29,000
Weir Structure	1	JOB	LS	40,000
		Subtotal		$69,000
		Contingency ± 25%		17,000
		TOTAL		$86,000

OPERATION AND MAINTENANCE COSTS

		Total Cost
Labor		$9,000
Materials		4,000
Equipment		3,000
	Subtotal	$16,000
	Contingency ± 25%	4,000
	TOTAL	$20,000

C16

COSTS OF CHEMICAL PRECIPITATION BY LIME ADDITION FOR UPLAND AND NEARSHORE DISPOSAL SITES
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Time Feed Station	1	JOB	LS	$145,000
Upflow Solids Contact Clarifier	1	JOB	LS	500,000
Sludge Pumping	1	JOB	LS	50,000
		Subtotal		$695,000
		Contingency ± 25%		174,000
		TOTAL		$869,000

OPERATION AND MAINTENANCE COSTS

Chemical		$340,000
Energy		8,000
Maintenance Materials		4,000
Labor		19,000
	Subtotal	$371,000
	Contingency ± 25%	93,000
	TOTAL	$464,000

ACTIVATED CARBON COLUMNS AT UPLAND OR NEARSHORE DISPOSAL SITES
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Carbon Columns	15	EA	$220,000.00	$3,300,000
Carbon Regeneration	1	JOB	LS	700,000
		Subtotal		$4,000,000
		Contingency ± 25%		1,000,000
		TOTAL		$5,000,000

OPERATION AND MAINTENANCE COSTS

	Quantity	Unit	Unit Price	Total Cost
O&M	4	MO	$99,000	$396,000
		Contingency ± 25%		99,000
		TOTAL		$495,000

C18

COSTS FOR OZONATION AT UPLAND AND NEARSHORE DISPOSAL SITES
(January 1984 Prices)

	Quantity	Unit	Unit Price	Total Cost
Equipment	1	JOB	LS	$1,280,000
		Subtotal		$4,000,000
		Contingency ± 25%		320,000
		TOTAL		$1,600,000

OPERATION AND MAINTENANCE COSTS

	Quantity	Unit	Unit Price	Total Cost
O&M	4	MO	$60,000	$240,000
		Contingency ± 25%		60,000
		TOTAL		$300,000

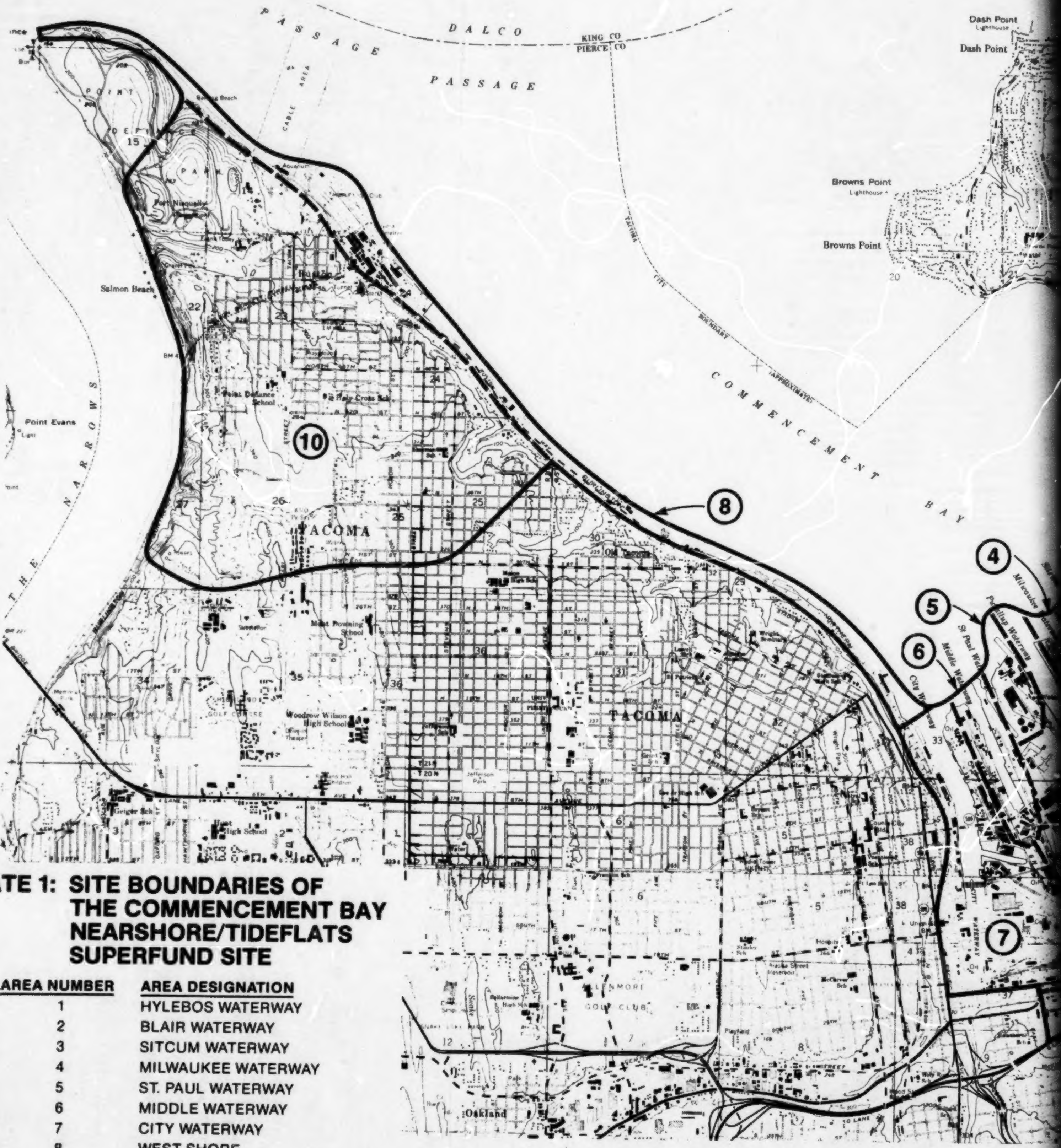
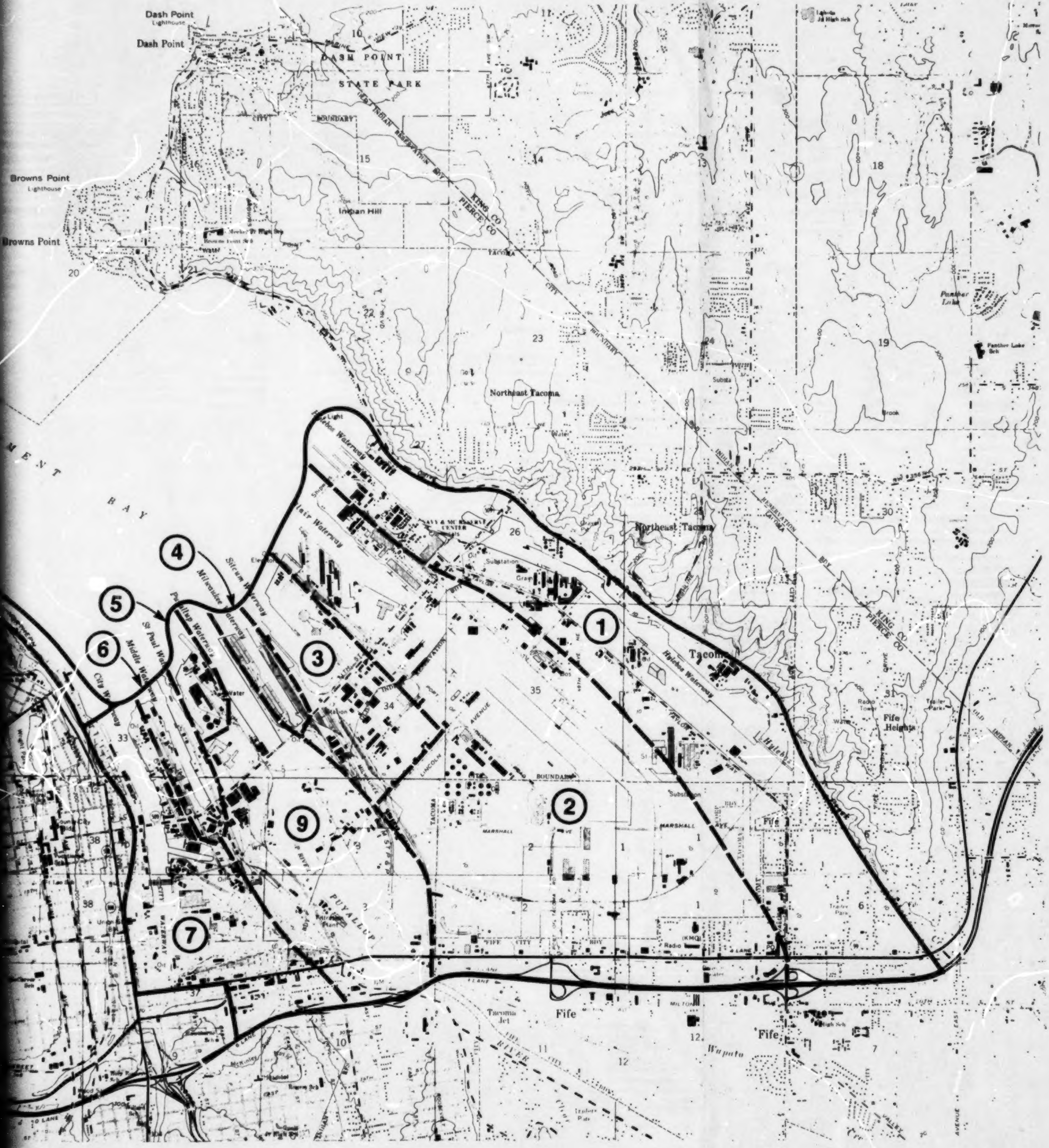


PLATE 1: SITE BOUNDARIES OF THE COMMENCEMENT BAY NEARSHORE/TIDEFLATS SUPERFUND SITE

AREA NUMBER	AREA DESIGNATION
1	HYLEBOS WATERWAY
2	BLAIR WATERWAY
3	SITCUM WATERWAY
4	MILWAUKEE WATERWAY
5	ST. PAUL WATERWAY
6	MIDDLE WATERWAY
7	CITY WATERWAY
8	WEST SHORE
9	PUYALLUP RIVER
10	RUSTON


Dash Point
Lighthouse
Dash Point
DASH POINT
STATE PARK
Browns Point
Lighthouse
Browns Point
Indian Hill
KING CO
PIERCE CO
INDIAN RESERVATION BDY
Northeast Tacoma
Panther Lake
MENT BAY
BAY
Hylebos Waterway
Blair Waterway
Sitcum Waterway
Milwaukee Waterway
Puyallup Waterway
St Paul Waterway
Middle Waterway
City Waterway
PUYALLUP
RIVER
Tacoma
Fife
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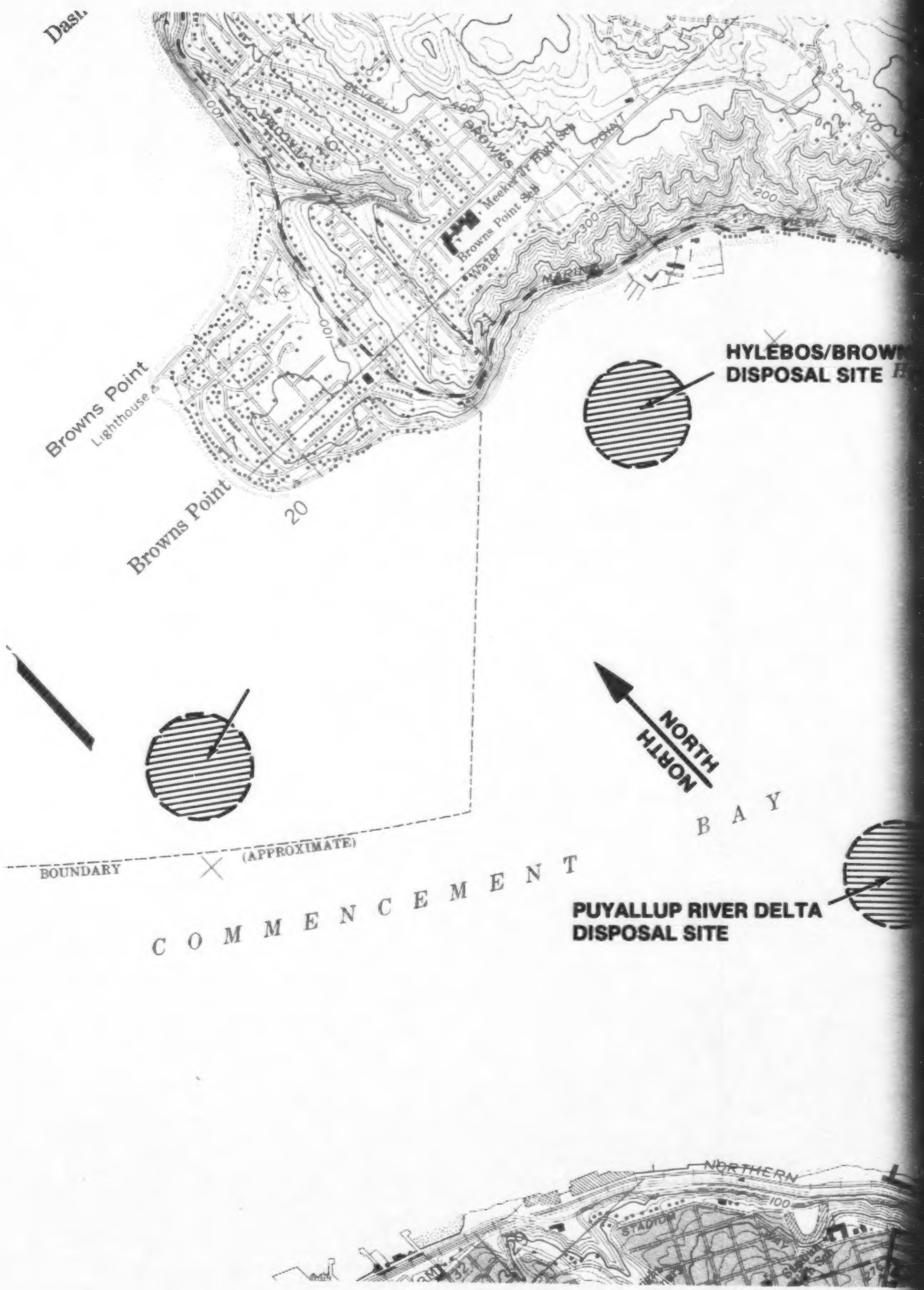
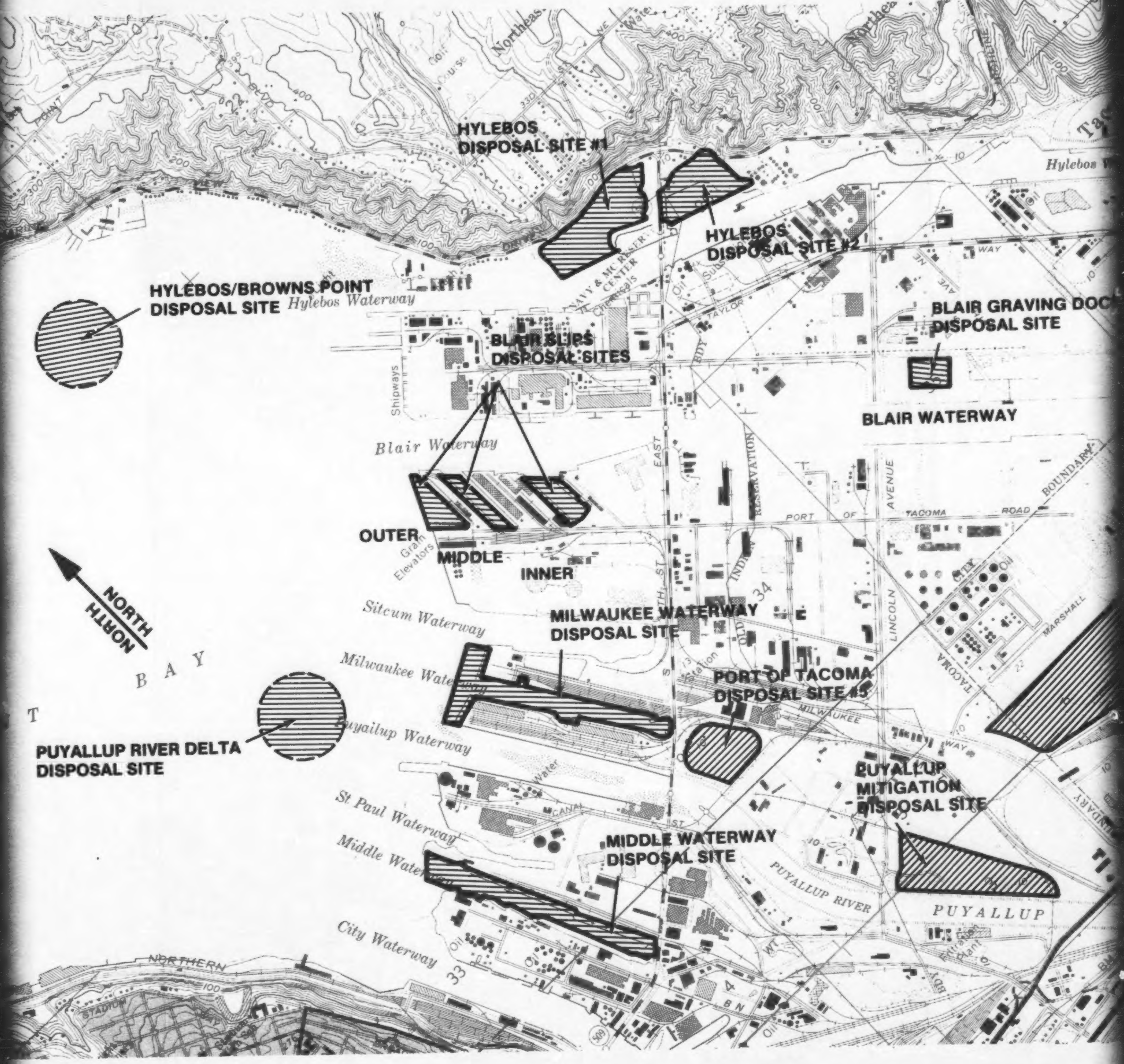
2
3
4
5
6
7
9


Das
Browns Point
Lighthouse
Meeker Jr High Sch
Browns Point Sch
Water
Point
Marine
100
200
300
400
Browns Point
20
HYLEBOS/BROWN
DISPOSAL SITE
NORTH
NORTH
BAY
BOUNDARY
(APPROXIMATE)
COMMENCEMENT
PUYALLUP RIVER DELTA
DISPOSAL SITE
NORTHERN
100
STADIUM


HYLEBOS DISPOSAL SITE #1
HYLEBOS DISPOSAL SITE #2
HYLEBOS/BROWNS POINT DISPOSAL SITE
Hylebos Waterway
BLAIR SLIPS DISPOSAL SITES
BLAIR GRAVING DOCK DISPOSAL SITE
BLAIR WATERWAY
Blair Waterway
Shipways
OUTER
MIDDLE
INNER
Grain Elevators
NORTH
BAY
Sitcum Waterway
Milwaukee Waterway
MILWAUKEE WATERWAY DISPOSAL SITE
PORT OF TACOMA DISPOSAL SITE #5
PUYALLUP RIVER DELTA DISPOSAL SITE
Puyallup Waterway
PUYALLUP MITIGATION DISPOSAL SITE
St Paul Waterway
Middle Waterway
MIDDLE WATERWAY DISPOSAL SITE
City Waterway
PUYALLUP RIVER
PUYALLUP
PORT OF TACOMA ROAD
LINCOLN AVENUE
EAST 11TH ST
MARSHALL
NORTHERN
Hylebos W

C21

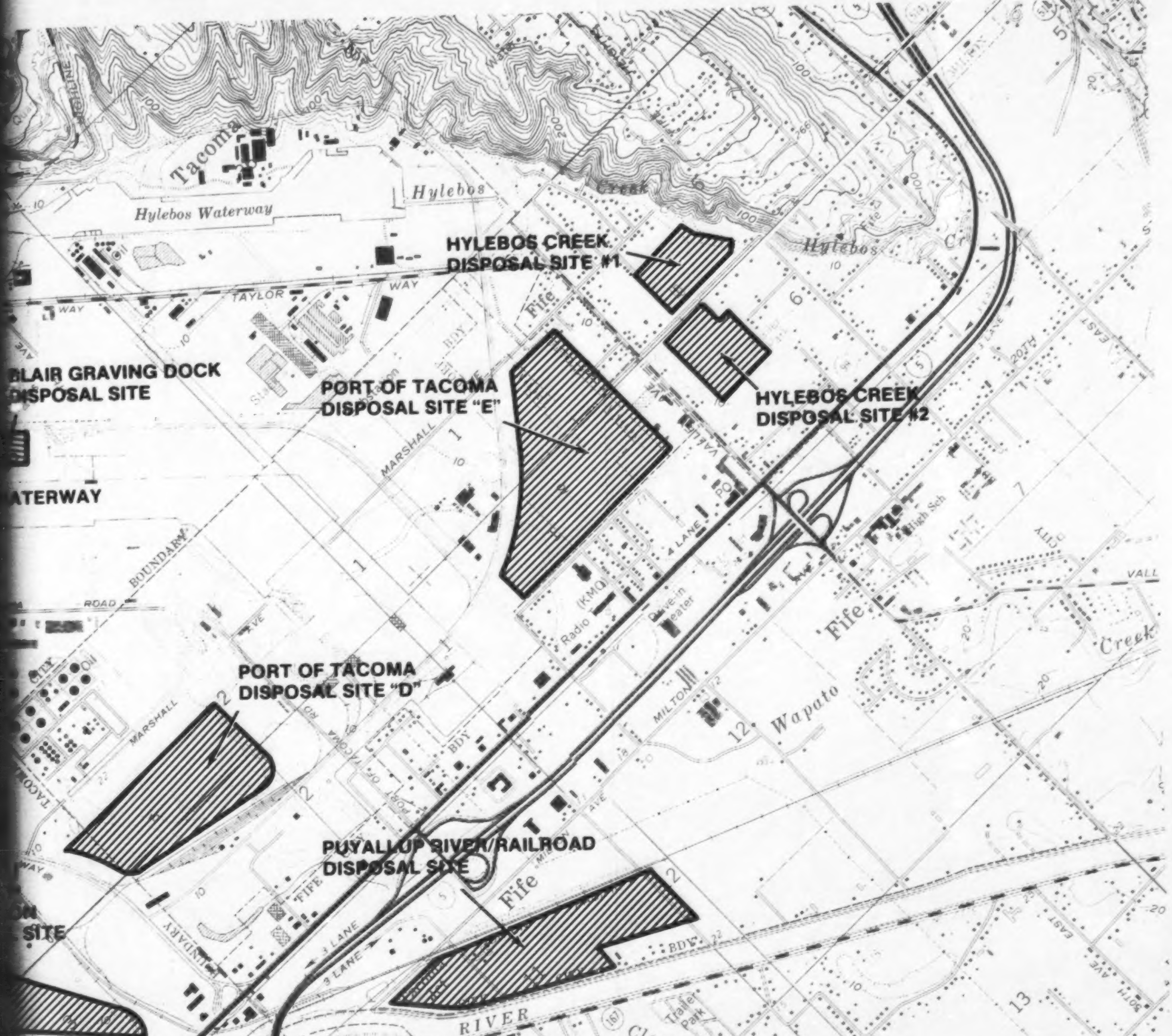


PLATE 2: POTENTIAL DISPOSAL SITES IN COMMENCEMENT BAY, WASHINGTON

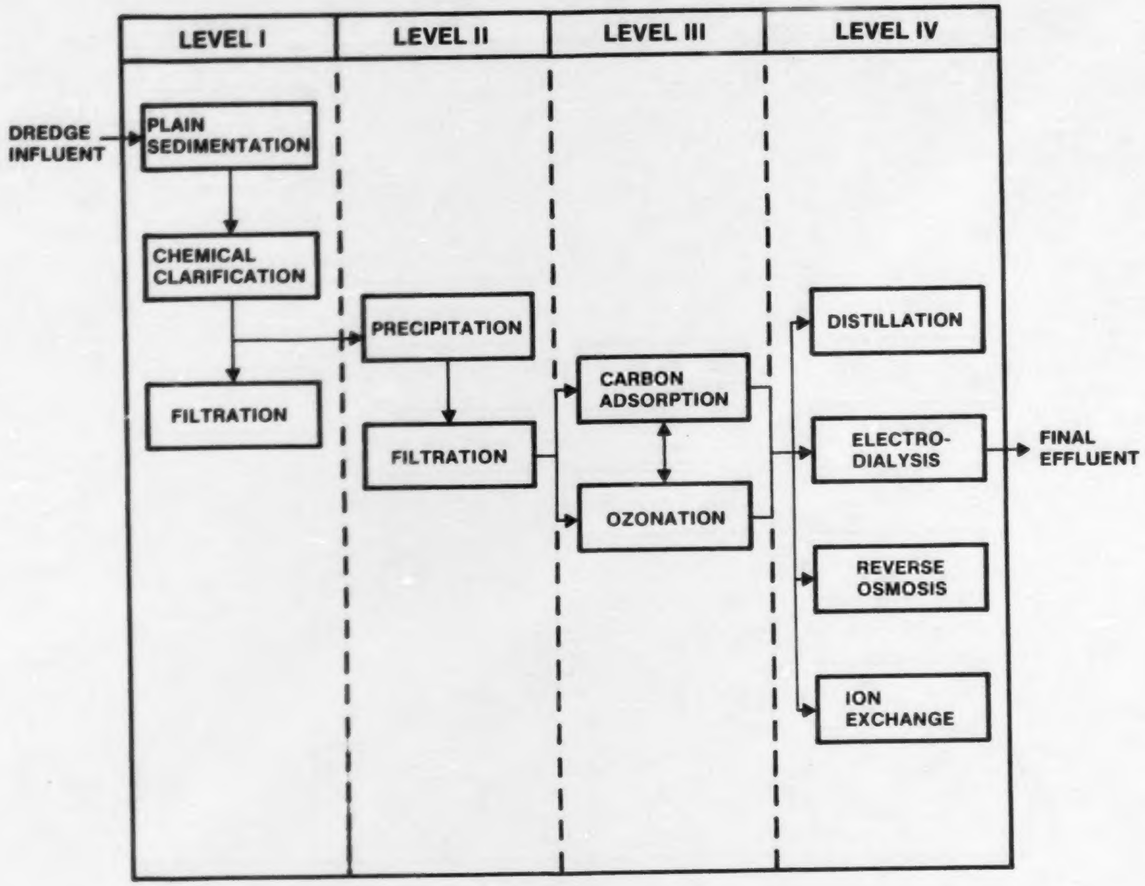


Plate 3: Treatment Processes Flow Diagram for Cost Estimating